INCAS

INtegrated model for the Competitiveness Assessment of Small-medium modular reactors

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USER MANUAL

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Foreword

The Integrated model for the Competitiveness Assessment of Small-medium modular reactors (INCAS) is a MATLAB code that allows the User to run scenario simulations about nuclear investment projects in new reactor fleet.

INCAS code allows the User great flexibility in the input parameters setting to represent different investment strategies and scenario conditions (electricity price, operating performances, sources of financing, etc.). In this way, sensitivity analysis are possible, to appreciate the impact of each input variable on the economic performance on the investment project or to set the most suitable investment strategy to reach the project objectives: i.e. LCOE minimisation, profitability maximisation, risk control, etc.

Moreover, the User can define some parameters as probability distribution and perform stochastic calculation; the program calculates many times the scenario, each time after sampling the distribution variables, and gives the expected value and the standard deviation of each result.

INCAS measures several indicators of performance, under different perspectives: financial soundness, cost-effectiveness, profitability, etc.

The User is allowed to save the scenario input settings, in order to recover them and, in case, modify selected parameters, running the program running the with new input value.

This manual is a guide for the Users who will make use of INCAS.

In the first section the basic concepts and the main used formulas will be explained; the following sections will explain in detail each window that can be encountered during INCAS execution.

MAIN CONCEPTS

Formulas and assumptions

Capital costs

The total saving factor is the product of:

- scale factor;
- modularization factor;
- multiple-unit factor;
- learning factor;
- design factor.

The scale factor is given by

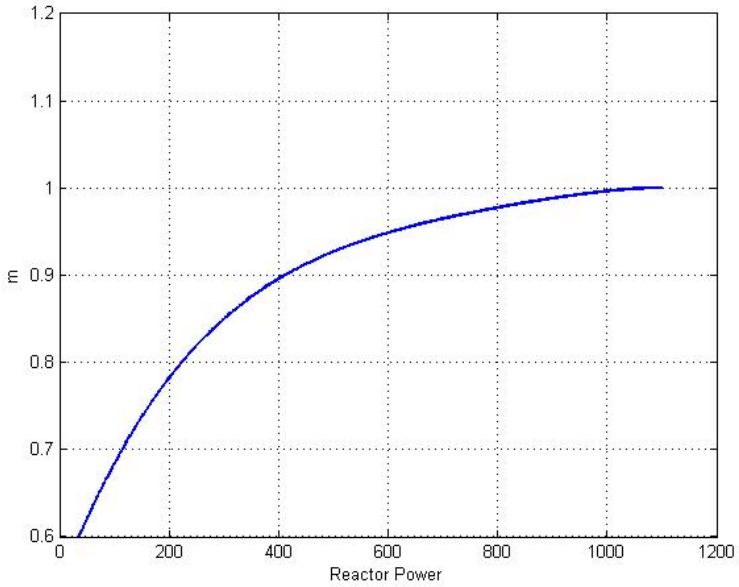
$$scale = \left(\frac{MW}{MW_{ref}}\right)^{-0.38}$$

so it goes from $+\infty$ to 0^{+}.

The modularization factor depends on the reactor type (i.e. its size p) according to:

$$m = \begin{cases} 0 & if\ p < 34\ MW \\ 1 & if\ p \geq 1100\ MW \\ -5.8174 \cdot 10^{-13} \cdot p^4 + 1.9304 \cdot 10^{-9} \cdot p^3 - 2.4992 \cdot 10^{-6} \cdot p^2 + \\ \quad +1.6 \cdot 10^{-3} \cdot p + 0.54691 & otherwise \end{cases}$$

and can be modified by the User.



The multiple-unit factor is given by

$$multiple = \frac{\left(1 + bb \cdot (S-1)\right)}{S}$$

where: S is the number of reactor units of the same type in construction (or already built) on the site; the asympthotic learning bb default value is 0.141, that can be changed by the User.

The learning factor for each reactor is influenced by 3 parameters:

- the number of reactors of the same type in construction (or already built) on a different site (W);
- the number of reactors of the same type on the same site which are at least 1/3 built (C).

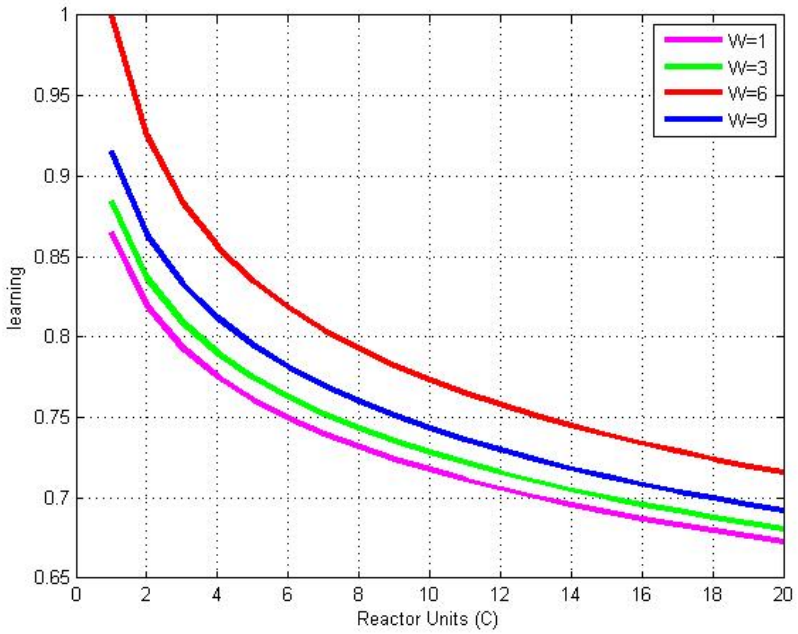
All these parameters linearly decay according to the oblivion parameters; the decay always starts when the last reactor is complete and stops when a construction starts.

The learning factor is expressed by default as:

$$learning = 0.48 \cdot (W + C)^{\alpha} + 0.41 \cdot (1 + W)^{\beta} \cdot C^{\gamma} + 0.11 \cdot (C)^{\delta}$$

where

$$\alpha = -0.0896733809708740$$
$$\beta = -0.0513991525066443$$
$$\gamma = -0.1281563514906820$$
$$\delta = -0.1520030934450500$$



It can be defined also by:

$$learning = (C)^{\frac{log(1-a)}{log2}} \cdot (1 + W)^{\frac{log(1-b)}{log2}}$$

if the User defines the parameters a and b.

The design factor depends on the reactor type.

The unitary overnight construction cost is given by the product of the total saving factor and the construction cost of a reference standard LWR.

The total overnight construction cost is obtained by taking into consideration the effect of construction delay. The delay-influenced cost fraction is increased by a factor:

$$\left(1 + escalation_{delay}\right)^{\frac{ConstrDuration_{eff} - ConstrDuration_{ref}}{4}}$$

The capital cost expenditure is distributed according to a sine function in the interval [0, π].

Relation between different reactors

All the reactors contribute to a common money pool, where the reactors with positive Unit Cash Flow (UCF) put the money left after paying financial interests and debt stock amortization quota; from this pool, the reactors with negative UCF can withdraw the amount they need to balance their cash flow.

UCF which are still negative are covered with debt and equity investment mix defined by the User.

If the total equity stock becomes negative, the investment is considered as failed due to bankruptcy and the calculation is stopped.

Dividends

Dividends, similarly to taxes, are calculated on the global net profit.

O&M cost

The O&M cost is given by the formula

$$OM(t) = \frac{OM_{unit} \cdot (1 + inflation)^{\frac{t-1}{4}}}{1 - OM_{variable} \cdot \frac{CF(t)}{\overline{CF}}} \cdot \frac{MW}{4}$$

Decontamination & Decommissioning cost

The D&D cost is given by the formula

$$factor_{DD} = 1{,}995024876 - 0.001 \cdot MW$$

$$begin_{DD} = DD_{ref} \cdot factor_{DD} \cdot MW$$

$$DD_{final} = begin_{DD} \cdot (1 + inflation)^{\frac{life + DDstart}{4}}$$

Electricity cost model

According to the mean reversion model, the electricity price for each period t is given by the formula

$$ee(t+1) = ee(t) + speed \cdot \left\{lrm \cdot \left[1 + (1 + trend)^{1/4} - 1\right] \cdot t - ee(t)\right\} + res\_std \cdot \varepsilon$$

where ε is a random variable distributed according to a normal distribution with null mean and unitary standard deviation

Cost of debt

Unless the User chooses a constant value for it, the cost of debt is

$$Kd = rfr + premium + extra$$

before the renegotiation, and

$$Kd = rfr + premium$$

afterwards.

The risk premium is given by the following table:

DE=Debt/(Debt+Equity)	Risk premium
DE ≤ 10%	0.30 %
10% < DE ≤ 20%	0.80 %
20% < DE ≤ 30%	1.25 %
30% < DE ≤ 40%	1.75 %
40% < DE ≤ 50%	2.50 %
50% < DE ≤ 60%	3.25 %
60% < DE ≤ 70%	5.00 %
70% < DE ≤ 80%	6.75 %
DE > 80%	9.00 %

Optimal financial mix

The optimal financial mix is the debt-equity mix to be used when covering negative cash flows in order to maximize the profit.

The NPV is calculated for different mix values and the one which gives the maximum value is considered to be the optimal mix; the result belongs to the interval:

$$[OPT - tol, OPT + tol]$$

where OPT is the exact solution and tol the tolerance chosen by the User.

If the User chooses a fixed cost of debt, the optimal financial mix is not calculated as its value is either 0%, if the cost of debt is lower than the one of equity, or 100% otherwise.

Levelised Cost Of Electricity (LCOE)

The LCOE is calculated by means of the bisection method.

Construction delays

The delay duration is determined by sampling. The delay quarters are then added to the expected construction duration, so obtaining the real construction duration.

If the construction shift option is enabled, the delay start instant is chosen randomly between the start and the expected end of the construction. Then, all the reactors which construction start is subsequent to the delay start, have their construction start instant increased by the delay duration.

I/O Files

The INCAS program reads and write three different file types, each one with a different function.

MAT files

The MAT file (MATLAB workspace files) created by INCAS contains all the variables needed to run the program without performing the User input operation.

Each file is characterized depending on the informations contained (input only or input and output) and the associated calculation type (deterministic or stochastic).

Files created for a calculation type cannot be used for the other one, and cannot be converted in any way. On the contrary, input files can be converted into input and output files by running the program and saving the results.

Files of this type cannot be created by the User without using INCAS.

EXC files

The EXC file (Microsoft Excel spreadsheet) created by INCAS is a summary of the input data and of the output results.

It is organized according to a base format file, which must be attached to the INCAS program (in the same folder of the EXE file).

This file represents only a way to present the final results in a clear way, while it cannot be used as input file.

CSV files

The CSV format (Comma-Separated Values) is used for the construction strategy files.

As defining a construction strategy by means of the GUI may be long, the User can write the strategy in a CSV file (by means of a spreadsheet application or a simple word processor) with significant time saving. On the other hand, the file must follow strict syntax rules (listed at the end of this section) and it is much easier making errors.

The program can also create a CSV file starting from an existing construction strategy; the so created file can be useful to perform massive changes and to make oneself familiar with this alternative input way.

Syntax rules:

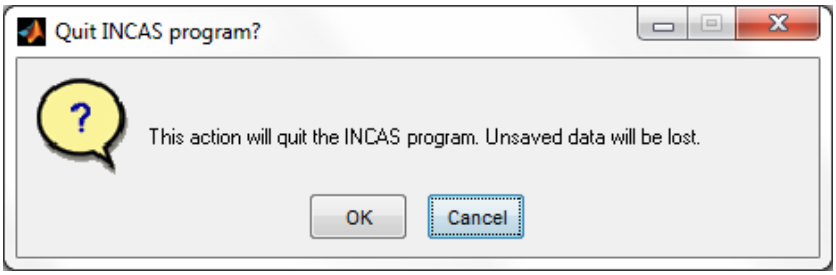
- One line corresponds to a single reactor;
- The values in a line must be separated by the semicolon (;);
- The number of reactors must be the one declared in Investment Input window (see later);
- The reactor type must be expressed as a number representing the place in the reactor library;
- This order in the values must be followed:
  - For deterministic calculation: reactor type, site number, construction start, construction duration;

- For stochastic calculation: reactor type, site number, construction start, delay distribution parameters (6 values: distribution type, mean/mode, st. deviation/lower cut, minimum, maximum, higher cut), D&D parameters (2 values: rate of return, D&D operation start);

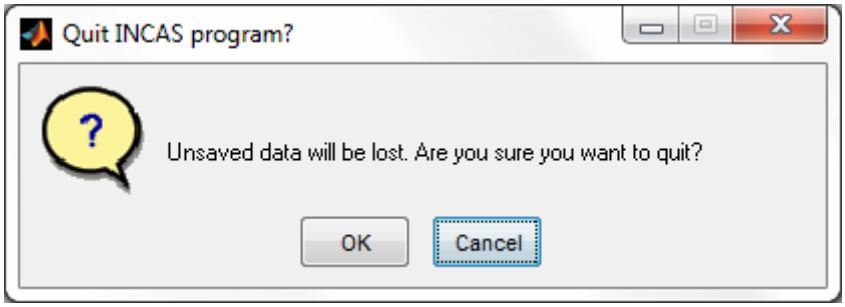
- Comment lines can be included by starting the line with a double slash (//).

Quitting program

On each primary input window of the INCAS program there is a QUIT buttons, which is the only way to quit the program properly. Using other methods for closing the window, such as the close button in the menu bar will provoke the appearance of a warning box asking for quit confirmation.



Nevertheless, also quitting by means of the proper QUIT button will require a confirmation by the User.



The INCAS program automatically quit once the calculation is finished.

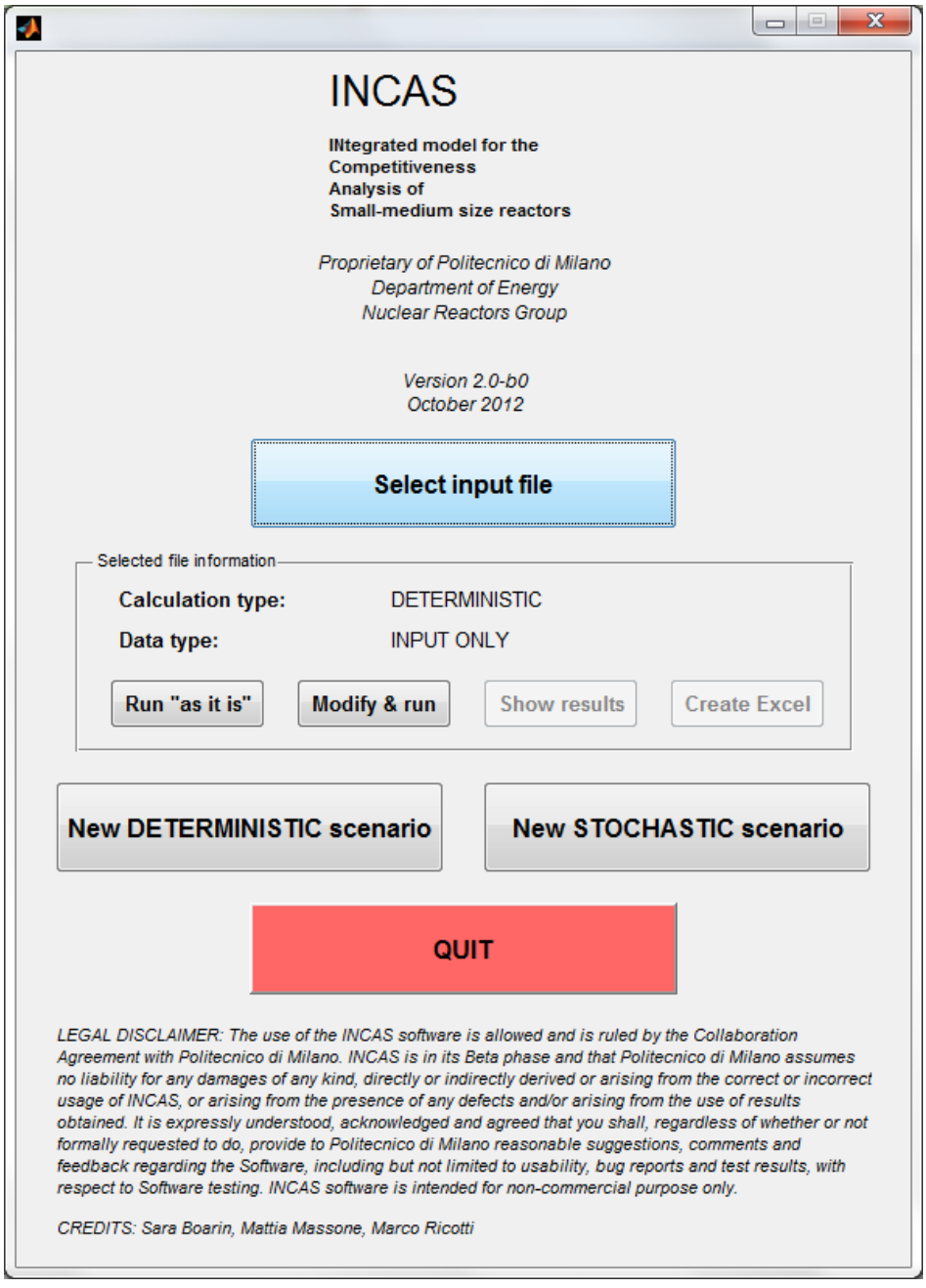
BASIC INPUT

Main menu

Window display

At program launch.

Screenshot


INCAS
INtegrated model for the
Competitiveness
Analysis of
Small-medium size reactors
Proprietary of Politecnico di Milano
Department of Energy
Nuclear Reactors Group
Version 2.0-b0
October 2012
Select input file
Selected file information
Calculation type:
DETERMINISTIC
Data type:
INPUT ONLY
Run "as it is"
Modify & run
Show results
Create Excel
New DETERMINISTIC scenario
New STOCHASTIC scenario
QUIT
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CREDITS: Sara Boarin, Mattia Massone, Marco Ricotti

Aim

The window present the User with the choice between:

- defining a new deterministic scenario;

- defining a new stochastic scenario
- opening an input scenario.

In this last case, the User selects a file and chooses between:

- running the input file without modifications;
- modifying the input scenario before running it;
- showing the results of an already calculated scenario;
- converting an already calculated scenario into an Excel output file.

Operating method

At start the User may choose between 3 buttons:

- **New DETERMINISTIC scenario**
- **New STOCHASTIC scenario**
- **Select input file**

The first two buttons close the current window and open the next one (Reactor library) in order to define a new scenario; once chosen, the calculation type cannot be changed without closing INCAS and the created files cannot be used for the other calculation type.

After clicking on the last button the User is asked to choose a MAT file, previously created with INCAS, to load. Then, a panel reporting the calculation type associated with the file (which cannot be changed in any way) and the information contained in it (input scenario or input&output) is shown. The panel contains 4 buttons, which may be or not enabled depending on the data type:

- **Run "as it is"**: closes the current window and starts the calculation based on the loaded file, without any change in the scenario;
- **Modify & run**: closes the current window and open the next one (Reactor library) in order to modify the loaded data;
- **Show results** (*for input&output files only)*: closes the current window and shows the output results contained in the file, without running again the calculation;
- **Create Excel** (*for input&output files only)*: closes the current window and creates and Excel file with the output results contained in the file, without running again the calculation.

Differences between deterministic and stochastic calculation

None.

Reactor library

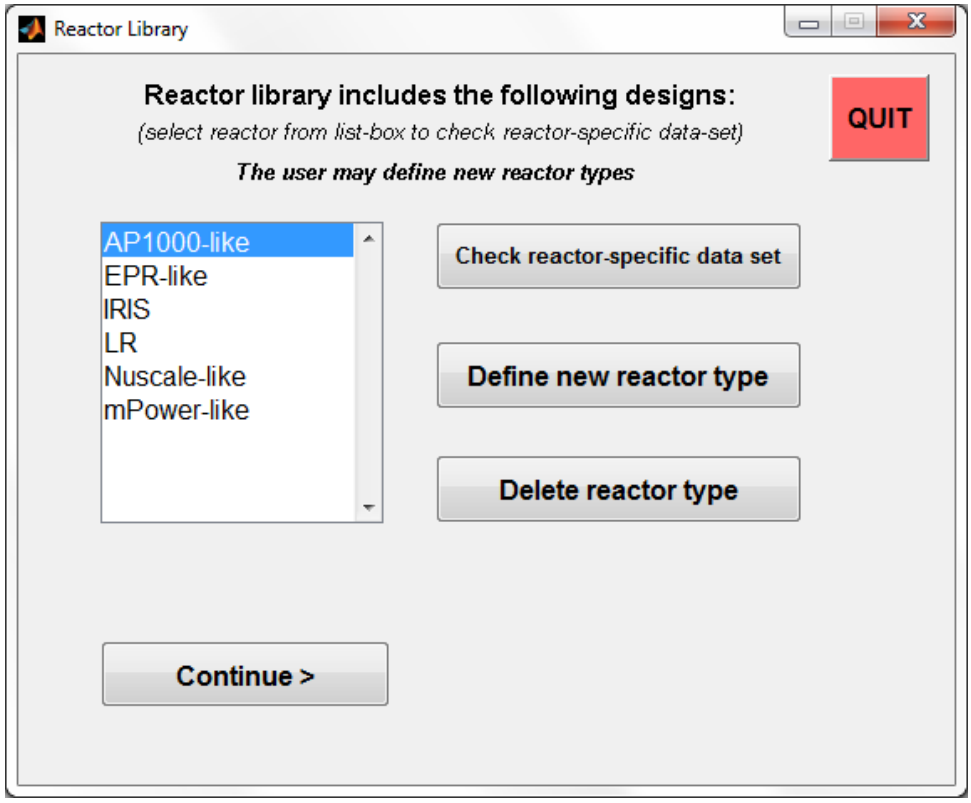
Window display

After Main menu;

Back from Investment Input;

Going back to the Basic Input from Input Finalization.

Screenshot



Aim

This User interface is the first window of the new scenario definition procedure. The User is presented with a default reactor library (different depending on the calculation type), which may be changed by:

- changing data of a reactor already included in the library;
- adding a new reactor to the library;
- deleting a reactor from the library.

Operating method

The list on the left side shows the reactors in the library and can be used to select the reactor to take into consideration. The features of this reactor can be displayed and modified by the

button **Check reactor-specific data set**, which loads a "Reactor data set" window. Otherwise, the reactor can be erased from the library with the button **Delete reactor type**.

It is also possible to define new reactors types from scratch with the button **Define new reactor type**, which opens an empty "Reactor data set" window.

When the reactor library definition is complete, the User may pass to the next window by clicking **Continue** (provided that the library is not completely empty).

Differences between deterministic and stochastic calculation

The default reactor library is different in the two cases.

Additional details

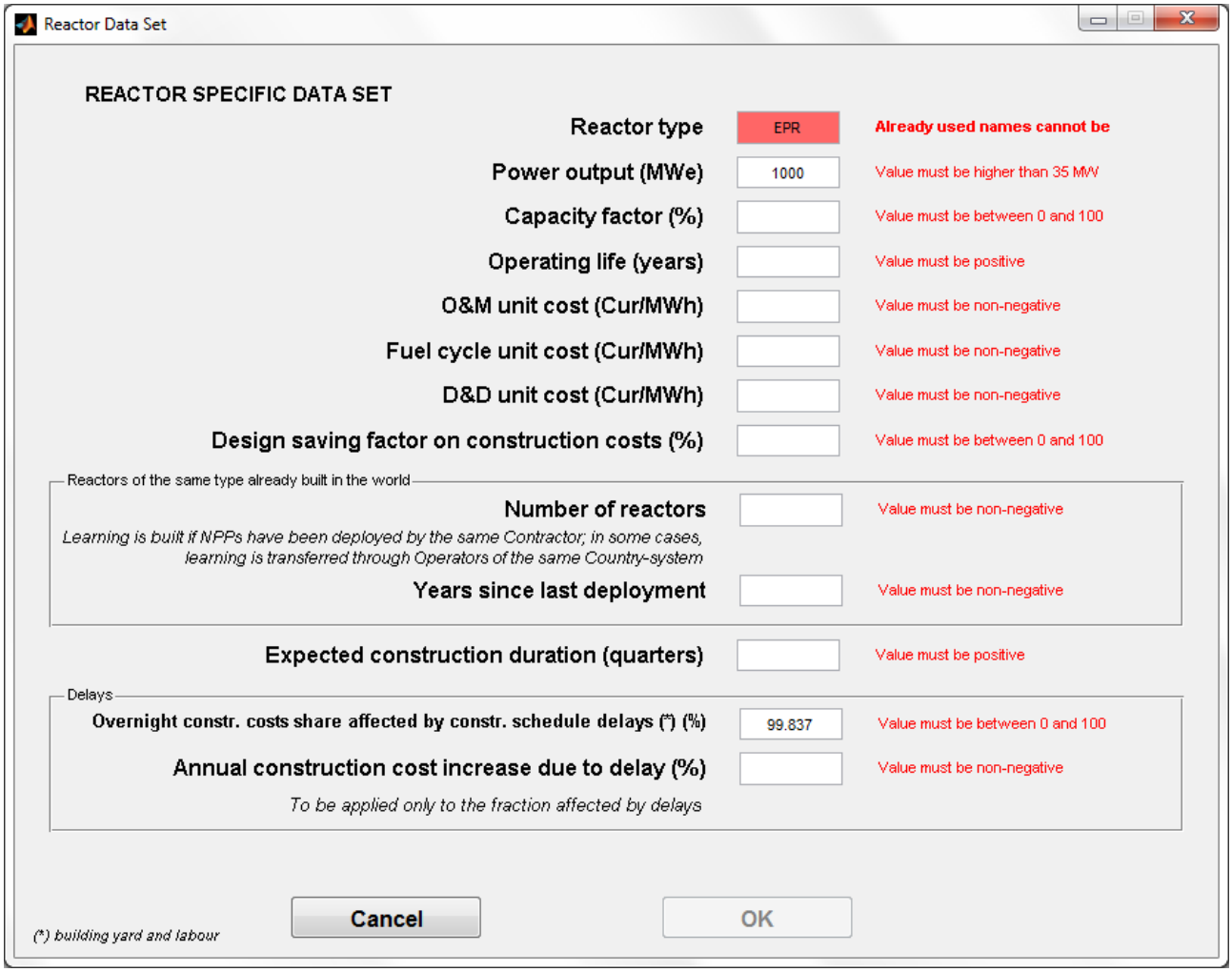
If the construction strategy has already been set and a reactor is deleted, the strategy is kept; however, if the deleted reactor is in use, its design is substituted with the first one in the library.

Reactor Data Set

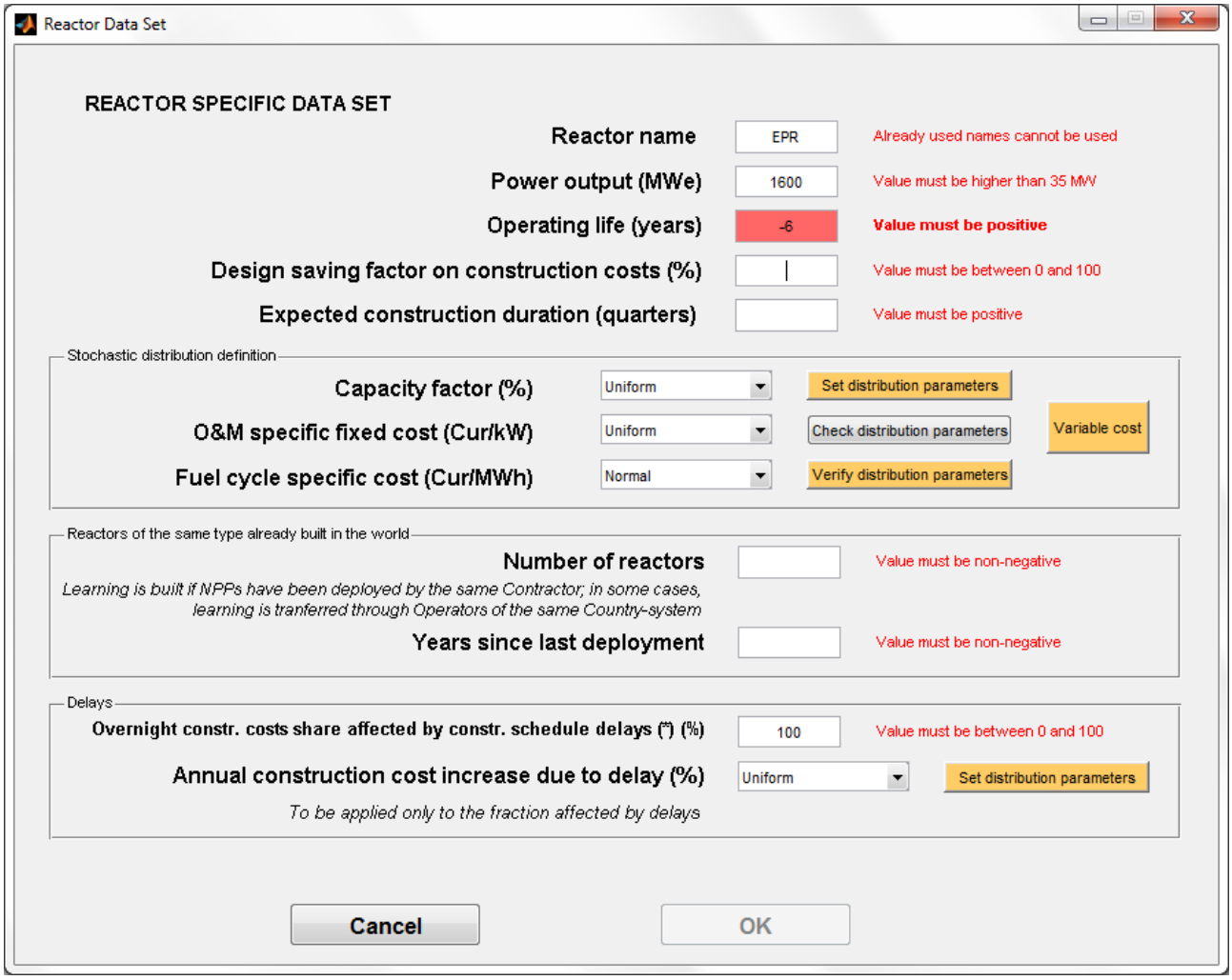
Window display

Accessible only from Reactor library.

Screenshot (deterministic)


Reactor Data Set
REACTOR SPECIFIC DATA SET
Reactor type
EPR
Already used names cannot be
Power output (MWe)
1000
Value must be higher than 35 MW
Capacity factor (%)
Value must be between 0 and 100
Operating life (years)
Value must be positive
O&M unit cost (Cur/MWh)
Value must be non-negative
Fuel cycle unit cost (Cur/MWh)
Value must be non-negative
D&D unit cost (Cur/MWh)
Value must be non-negative
Design saving factor on construction costs (%)
Value must be between 0 and 100
Reactors of the same type already built in the world
Number of reactors
Learning is built if NPPs have been deployed by the same Contractor; in some cases, learning is transferred through Operators of the same Country-system
Value must be non-negative
Years since last deployment
Value must be non-negative
Expected construction duration (quarters)
Value must be positive
Delays
Overnight constr. costs share affected by constr. schedule delays (*) (%)
99.837
Value must be between 0 and 100
Annual construction cost increase due to delay (%)
Value must be non-negative
To be applied only to the fraction affected by delays
(*) building yard and labour
Cancel
OK

Screenshot (stochastic)


Reactor Data Set
REACTOR SPECIFIC DATA SET
Reactor name
EPR
Already used names cannot be used
Power output (MWe)
1600
Value must be higher than 35 MW
Operating life (years)
-6
Value must be positive
Design saving factor on construction costs (%)
Value must be between 0 and 100
Expected construction duration (quarters)
Value must be positive
Stochastic distribution definition
Capacity factor (%)
Uniform
Set distribution parameters
O&M specific fixed cost (Cur/kW)
Uniform
Check distribution parameters
Variable cost
Fuel cycle specific cost (Cur/MWh)
Normal
Verify distribution parameters
Reactors of the same type already built in the world
Number of reactors
Value must be non-negative
Learning is built if NPPs have been deployed by the same Contractor; in some cases, learning is tranferred through Operators of the same Country-system
Years since last deployment
Value must be non-negative
Delays
Overnight constr. costs share affected by constr. schedule delays (*) (%)
100
Value must be between 0 and 100
Annual construction cost increase due to delay (%)
Uniform
Set distribution parameters
To be applied only to the fraction affected by delays
Cancel
OK

Aim

This window is used for adding new reactors or to modify existing ones in the reactor library. The User is asked the features peculiar to the reactor, expressed as 13 values to be introduced.

Operating method

The User should fill the **edit boxes** with the required data, complying with the corresponding constraints; failing this, the violating edit box is shaded in red and the violated constraint is written in bold. In addition, the User cannot finalize the reactor definition/modification.

Once every edit box has been properly filled the definition/modification can be finalized by clicking **OK**. It is always possible to abort a new reactor definition by means of the **Cancel** button, while it is not possible when modifying an existing reactor.

Differences between deterministic and stochastic calculation

Only for the stochastic calculation, some data are substituted with distributions. The distribution parameters can be set by clicking the **Set/Verify/Check parameters** button (a

"Distribution parameters" window will open), after selecting the distribution type from the **menu**.

At start each distribution button caption is "Set parameters" and it has a yellow background colour; similarly, right after changing the distribution choice the caption becomes "Verify parameters" and the background colour is yellow. Once the buttons have been clicked, the caption becomes "Check parameters". The User can finalize the operation only after each distribution has been set/verified and the edit boxes are all filled.

The stochastic version of the window also has the **Variable cost** button, which launches the "Variable O&M costs" window.

Additional details

As the parameters of a triangular distribution are not compatible with the ones of the other distributions, when changing the distribution selection from or to triangular one, the parameters for that distribution are deleted.

Variable O&M costs

Window display

Accessible only from Reactor Data Set *(stochastic calculation only)*.

Screenshot

Aim

The User is asked to introduce the variable O&M cost percentage.

Operating method

The User should fill the **edit box** with the required value; it must be non-negative, otherwise the violating edit box is shaded in red and the User cannot get back to the Reactor Data Set window by means of the **OK** button.

Differences between deterministic and stochastic calculation

The form is not used in deterministic calculation.

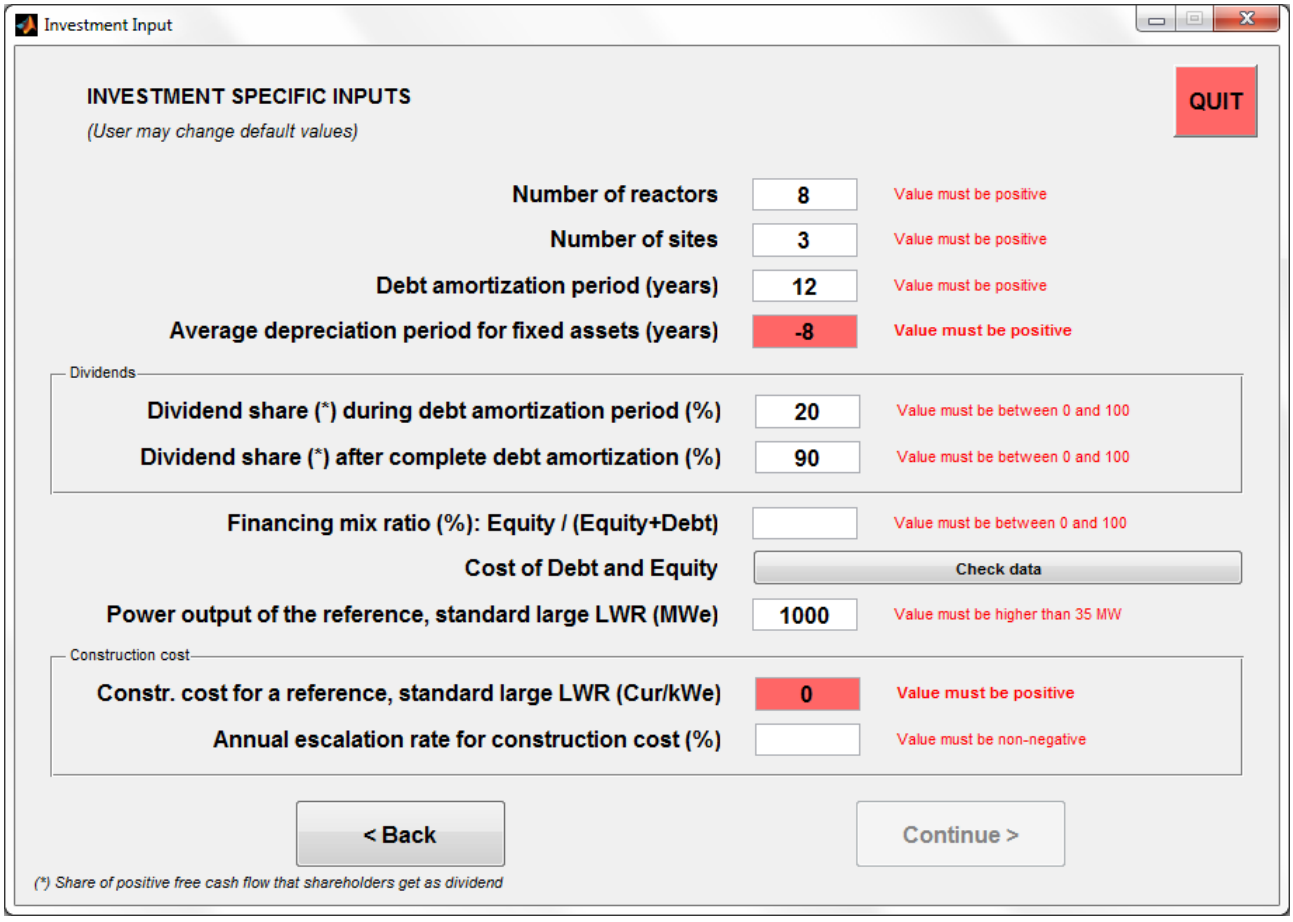
Investment Input

Window display

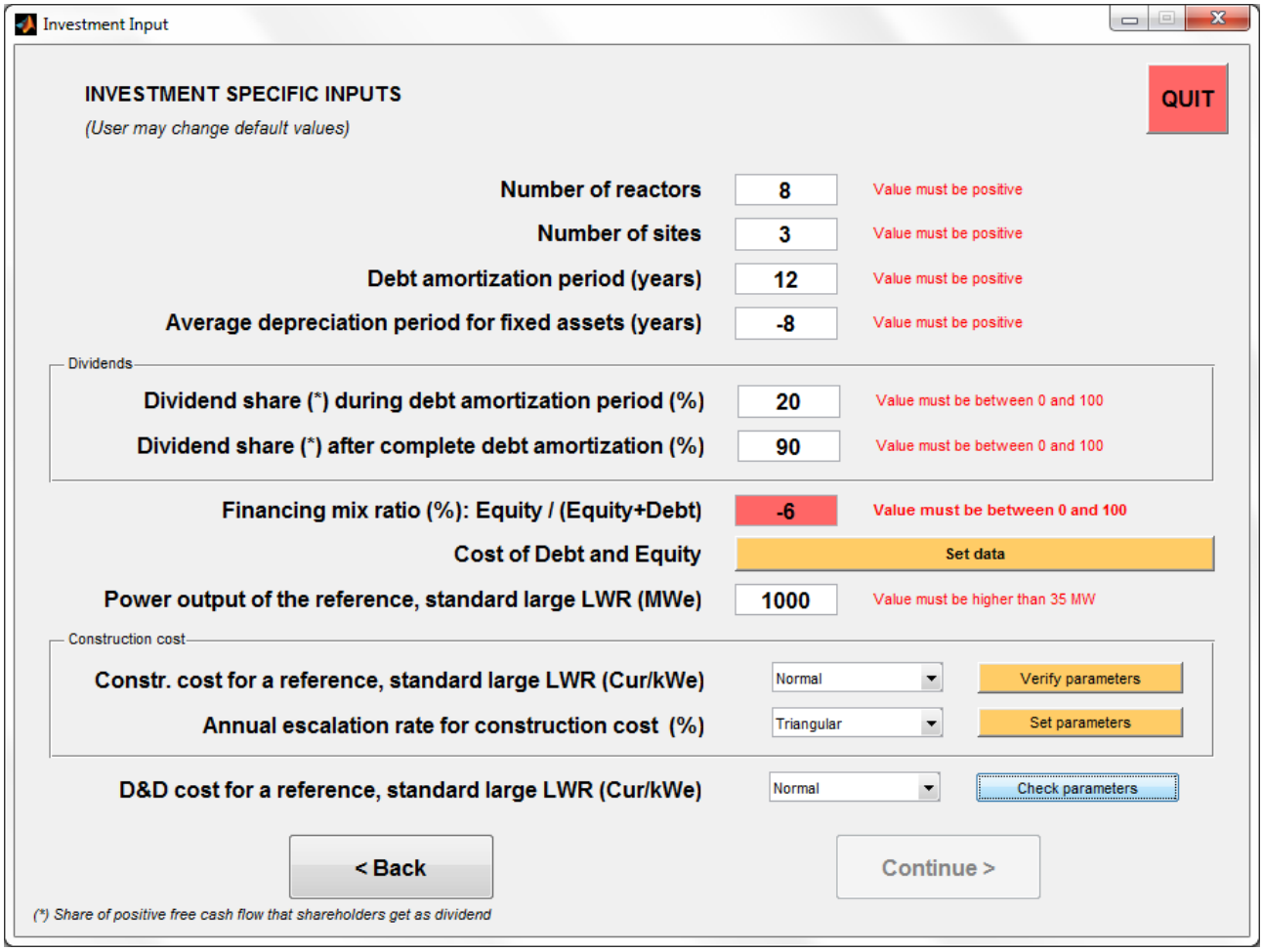
After Reactor library;

Back from Country Input.

Screenshot (deterministic)


Investment Input
INVESTMENT SPECIFIC INPUTS
(User may change default values)
QUIT
Number of reactors
8
Value must be positive
Number of sites
3
Value must be positive
Debt amortization period (years)
12
Value must be positive
Average depreciation period for fixed assets (years)
-8
Value must be positive
Dividends
Dividend share (*) during debt amortization period (%)
20
Value must be between 0 and 100
Dividend share (*) after complete debt amortization (%)
90
Value must be between 0 and 100
Financing mix ratio (%): Equity / (Equity+Debt)
Value must be between 0 and 100
Cost of Debt and Equity
Check data
Power output of the reference, standard large LWR (MWe)
1000
Value must be higher than 35 MW
Construction cost
Constr. cost for a reference, standard large LWR (Cur/kWe)
0
Value must be positive
Annual escalation rate for construction cost (%)
Value must be non-negative
< Back
Continue >
(*) Share of positive free cash flow that shareholders get as dividend

Screenshot (stochastic)


Investment Input
INVESTMENT SPECIFIC INPUTS
(User may change default values)
QUIT
Number of reactors
8
Value must be positive
Number of sites
3
Value must be positive
Debt amortization period (years)
12
Value must be positive
Average depreciation period for fixed assets (years)
-8
Value must be positive
Dividends
Dividend share (*) during debt amortization period (%)
20
Value must be between 0 and 100
Dividend share (*) after complete debt amortization (%)
90
Value must be between 0 and 100
Financing mix ratio (%): Equity / (Equity+Debt)
-6
Value must be between 0 and 100
Cost of Debt and Equity
Set data
Power output of the reference, standard large LWR (MWe)
1000
Value must be higher than 35 MW
Construction cost
Constr. cost for a reference, standard large LWR (Cur/kWe)
Normal
Verify parameters
Annual escalation rate for construction cost (%)
Triangular
Set parameters
D&D cost for a reference, standard large LWR (Cur/kWe)
Normal
Check parameters
< Back
Continue >
(*) Share of positive free cash flow that shareholders get as dividend

Aim

In this window the User is asked to introduce 11/12 values related to the investment.

Operating method

The User should fill the **edit boxes** with the required data, complying with the corresponding constraints; failing this, the violating edit box is shaded in red and the violated constraint is written in bold. In addition, the User cannot continue to the next window.

The cost of debt and equity parameters must be defined in a separate window, accessible with the **Set data** button. The window must be visited at least once (the yellow background indicates that this requirement has not been fulfilled yet) before continuing to the next form.

Once every edit box has been properly filled the User can pass to the following input window (Country Input) by clicking **Continue**. It is always possible to go back to the Reactor library by means of the **Back** button.

Differences between deterministic and stochastic calculation

Only for the stochastic calculation, some data are substituted with distributions. The distribution parameters can be set by clicking the **Set/Verify/Check parameters** button (a "Distribution parameters" window will open), after selecting the distribution type from the

menu.

At start each distribution button caption is “Set parameters” and it has a yellow background colour; similarly, right after changing the distribution choice the caption becomes “Verify parameters” and the background colour is yellow. Once the buttons have been clicked, the caption becomes “Check parameters”. The User can finalize the operation only after each distribution has been set/verified and the edit boxes are all filled.

Additional details

As the parameters of a triangular distribution are not compatible with the ones of the other distributions, when changing the distribution selection from or to triangular one, the parameters for that distribution are deleted.

When **Back** is clicked, the inserted data are kept.

If the number of reactors is changed, the data possibly previously inserted in the Construction Schedule might be deleted:

- if it is increased, the data are completely preserved;
- if it is reduced, the data are kept within the limits of the new n;
- if the cell is emptied, the data are completely lost.

Similarly, if the number of sites is changed:

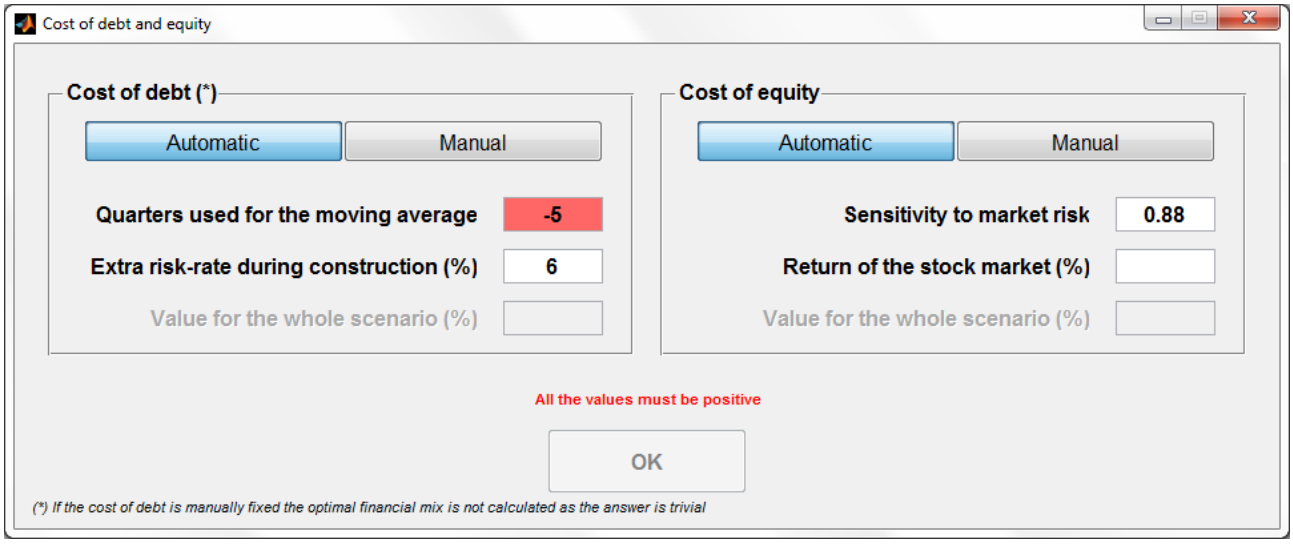
- if it is increased, the data are completely preserved;
- if it is reduced, the reactors built in sites with higher number than the new value, are set to the maximum value;
- if the cell is emptied, the data are completely lost.

Cost of debt and equity

Window display

Accessible from Reactor Data Set.

Screenshot


Cost of debt and equity
Cost of debt (*)
Automatic
Manual
Quarters used for the moving average
-5
Extra risk-rate during construction (%)
6
Value for the whole scenario (%)
Cost of equity
Automatic
Manual
Sensitivity to market risk
0.88
Return of the stock market (%)
Value for the whole scenario (%)
All the values must be positive
OK
(*) If the cost of debt is manually fixed the optimal financial mix is not calculated as the answer is trivial

Aim

The User interface allows changing the method used for calculating the cost of debt and equity and asks the User for the needed data.

Operating method

The User should choose the method for calculating the cost of debt and equity (automatic or manual) by means of the **buttons**; based on the choice, the right **edit boxes** are enabled, and the other ones are disabled. All the values must be positive, otherwise the violating edit box is shaded in red and the User cannot get back to the Investment Input window by means of the **OK** button.

Differences between deterministic and stochastic calculation

None.

Additional details

When the button selection is changed, only the second edit box value is kept, while the other ones are reset.

If the cost of debt selection is set to “Manual”, the optimal financial mix will not be calculated.

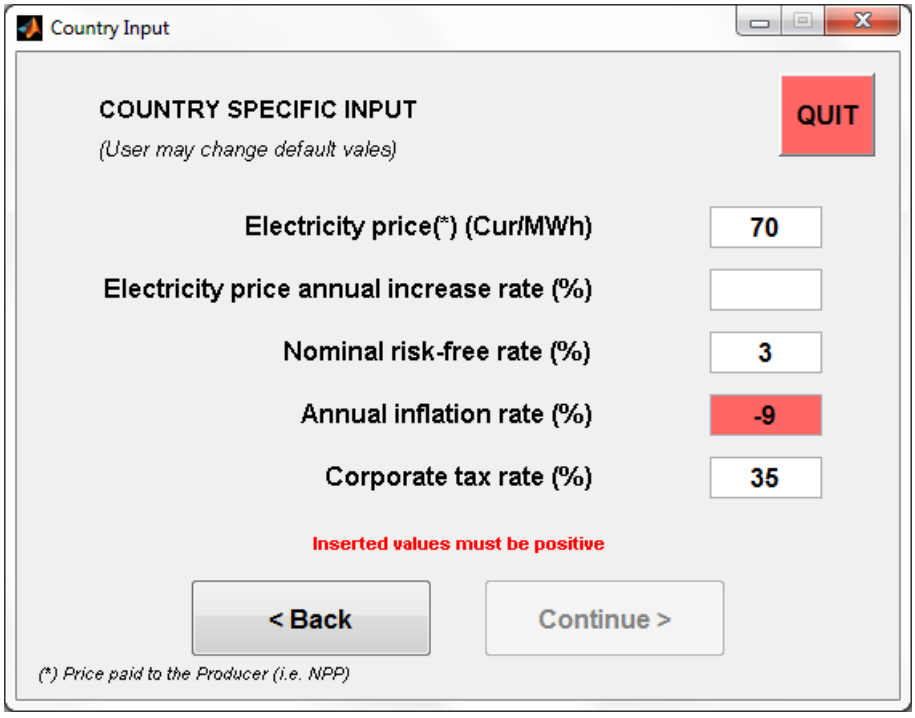
Country Input

Window display

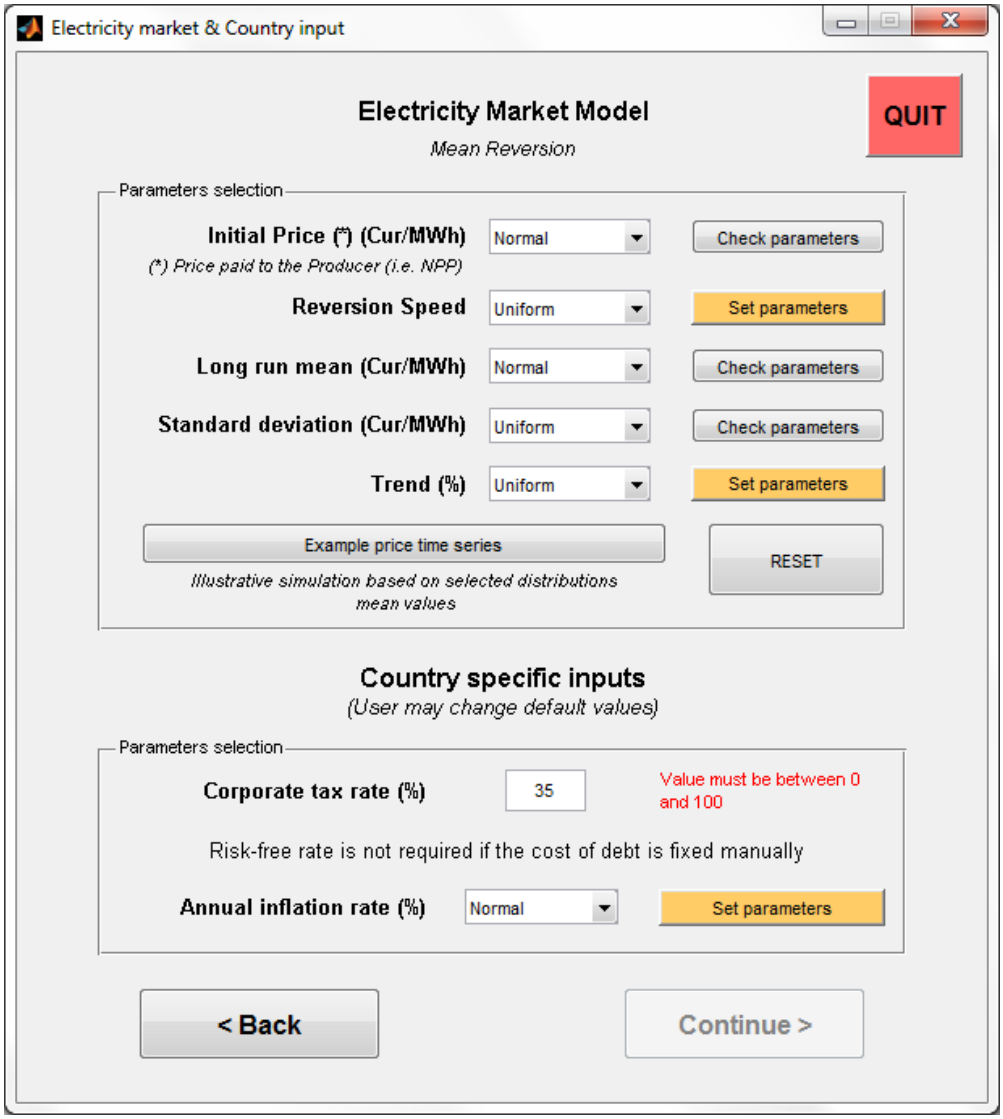
After Investment Input;

Back from Construction Schedule.

Screenshot (deterministic)



Screenshot (stochastic)



Aim

This User interface allows to introduce the electricity market and country specific inputs. The User is asked to introduce 5/8 values.

Operating method

The User should fill the **edit boxes** with the required data, complying with the corresponding constraints; failing this, the violating edit box is shaded in red and the violated constraint is written in bold. In addition, the User cannot continue to the next window.

Once every edit box has been properly filled the User can pass to the following input window (Construction schedule) by clicking **Continue**. It is always possible to go back to the Investment Input by means of the **Back** button.

Differences between deterministic and stochastic calculation

Only for the stochastic calculation, some data are substituted with distributions. The distribution parameters can be set by clicking the **Set/Verify/Check parameters** button (a "Distribution parameters" window will open), after selecting the distribution type from the

menu.

At start each distribution button caption is “Set parameters” and it has a yellow background colour; similarly, right after changing the distribution choice the caption becomes “Verify parameters” and the background colour is yellow. Once the buttons have been clicked, the caption becomes “Check parameters”. The User can finalize the operation only after each distribution has been set/verified and the edit boxes are all filled.

The default distribution parameters for the first part of the form can be restored with the **RESET** button.

Only for stochastic calculation, it is possible to produce a possible electricity price evolution based on the inserted distribution parameters by using the button **Example price time series**.

Additional details

As the parameters of a triangular distribution are not compatible with the ones of the other distributions, when changing the distribution selection from or to triangular one, the parameters for that distribution are deleted.

When the **Back** button is clicked, the inserted data are kept.

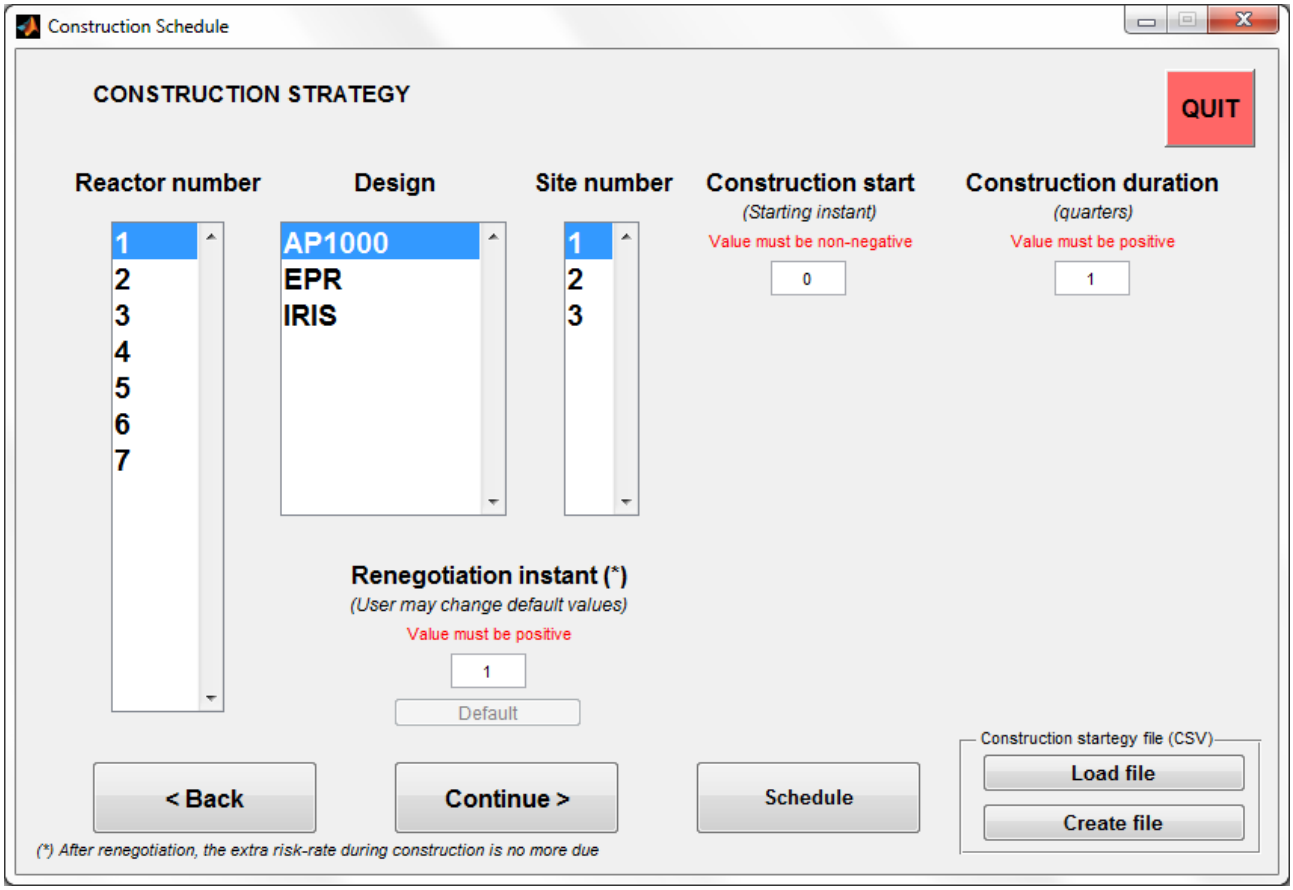
Construction Schedule

Window display

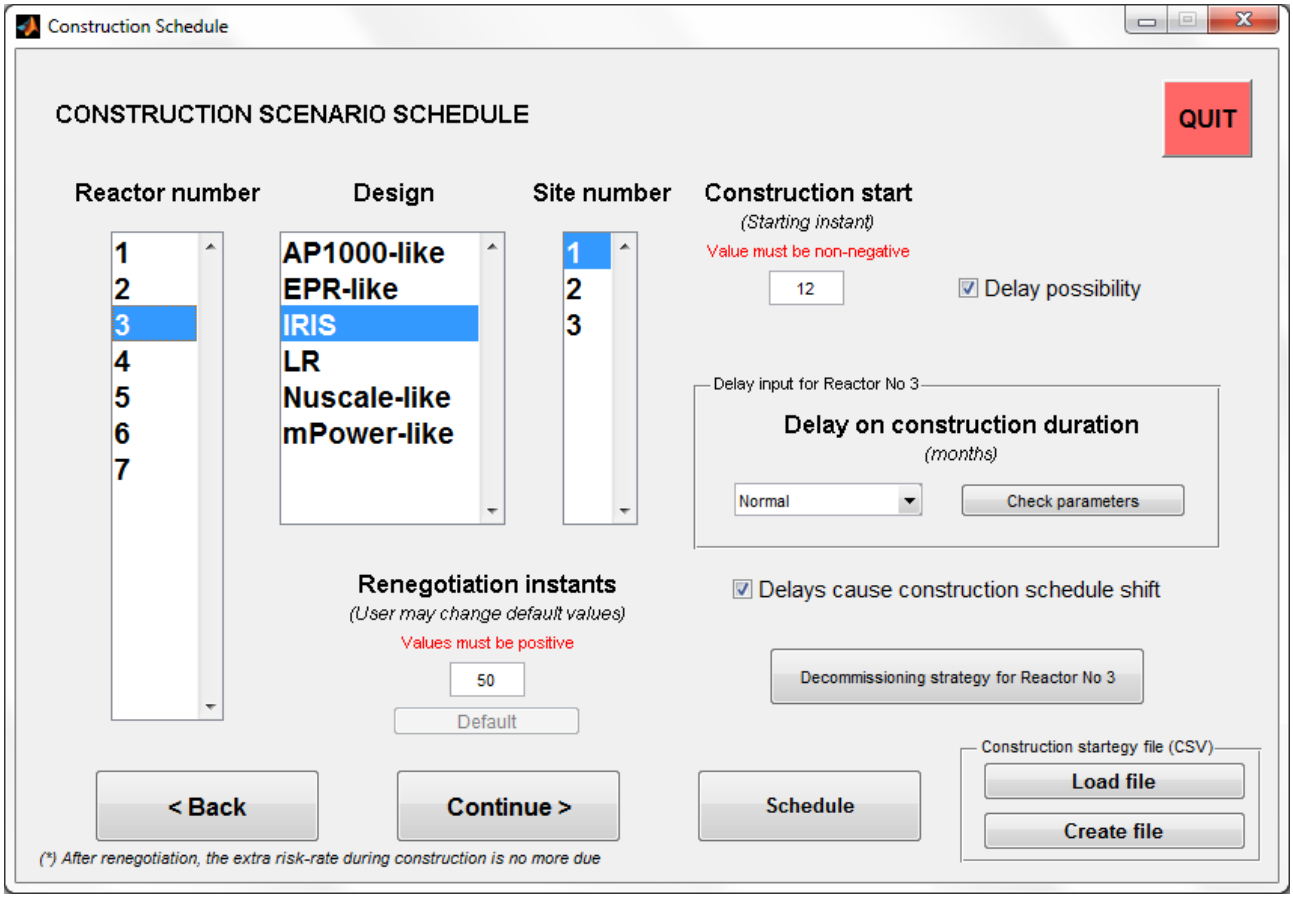
After Country Input;

Back from Number of simulations *(stochastic calculation only)*.

Screenshot (deterministic)



Screenshot (stochastic)



Aim

This window is used for defining the construction schedule (reactor type, site, construction start quarter, duration, delay parameters).

Operating method

For each reactor to be built (chosen with the **Reactor number** list) the reactor type and the site must be chosen (with the other two **lists**). In addition, the construction start quarter and the duration must be defined in the 2 **edit boxes**.

The default renegotiation instant, which changes depending on the declared construction schedule, can be changed by substituting the default value in the provided edit box. Once modified, the value will not be updated, but the default value can be restored by clicking the **Default** button; this will restore also the automatic update.

The User should fill the edit boxes with the required data, complying with the corresponding constraints; failing this, the violating edit box is shaded in red and the violated constraint is written in bold. In addition, the User cannot modify any other reactor than the selected one.

When the schedule definition is complete, the User may pass to the next window by clicking **Continue**. It is always possible to go back to the Country Input by means of the **Back** button.

The inserted schedule can be graphically visualized with the button **Schedule**, which is active with the same condition as the **Continue** one.

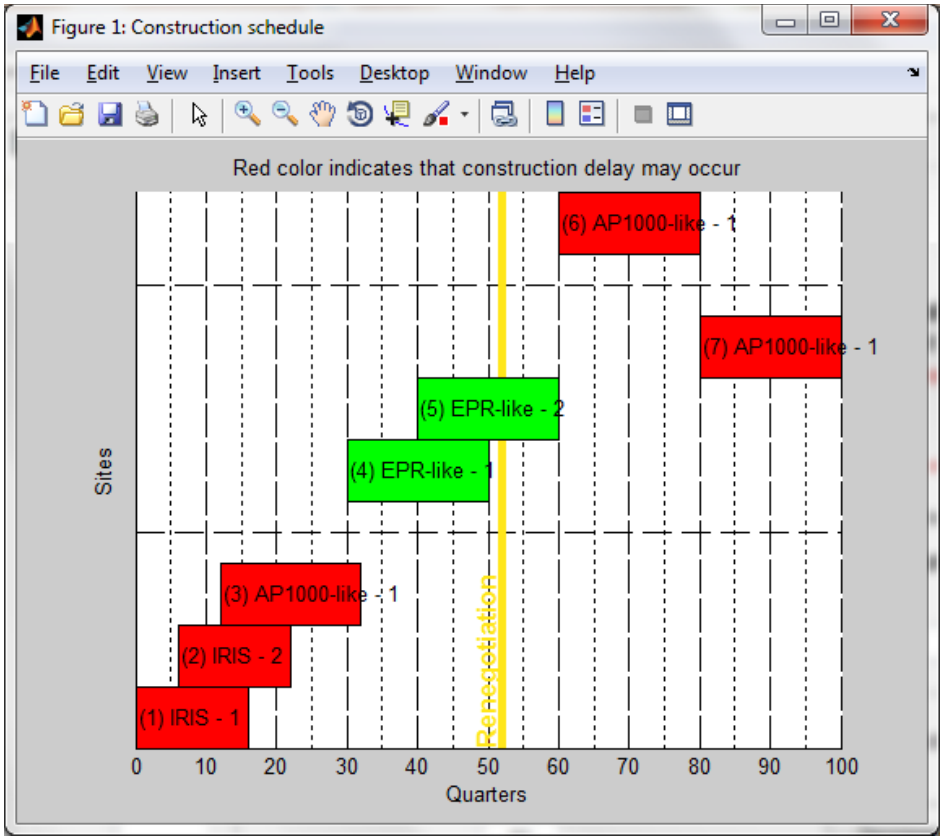


Figure 1: Construction schedule
File Edit View Insert Tools Desktop Window Help
Red color indicates that construction delay may occur
(6) AP1000-like - 1
(7) AP1000-like - 1
(5) EPR-like - 2
(4) EPR-like - 1
(3) AP1000-like - 1
(2) IRIS - 2
(1) IRIS - 1
Re-negotiation
Sites
0 10 20 30 40 50 60 70 80 90 100
Quarters

By means of the **Construction strategy file** panel it is possible to handle the schedule definition using CSV files rather than the graphical interface; in this way the time for the operation is decreased, but it requires more skills and it is easy to cause errors. For more information about CSV files in INCAS, please have a look to the I/O Files paragraph of this manual.

Differences between deterministic and stochastic calculation

Only for the stochastic calculation, the construction duration must not be introduced as it corresponds to the default value for the selected design modified depending on the delay parameters, which, on the contrary, must be introduced.

The delay duration is defined by means of a distribution, which can be customized by clicking the **Set/Verify/Check parameters** button (a "Distribution parameters" window will open), after selecting the distribution type from the **menu**. For each reactor it the User can introduce different parameters or disable the **delay possibility** operating on the special checkbox.

If the **Delays cause construction schedule shift** checkbox is enabled, the delay of each reactor will defer the construction start of all the reactors whose construction has not been started yet when the delay occurs. On the other hand, if it is disabled the construction of each reactor will not be exactly the one defined in the schedule.

Right after changing the distribution choice the distribution button caption becomes "Verify parameters" and the background colour is yellow. Once the buttons have been clicked, the caption becomes again "Check parameters". The User can finalize the operation only after each distribution has been set/verified and the edit boxes are all filled.

Moreover, for each reactor the **Decommissioning strategy** can be changed by means of the button provided, which will open a special window. If not modified, the strategy is the default

one.

Additional details

At start all the reactors are of the first type and in the first site; the reactor starts at instant 0 and the duration is one quarter.

The debt renegotiation occurs by default at the quarter, according to the formula:

$$reneg = ceil\left[\frac{\sum_i^n (Cstart_i + Cdur_i)}{n}\right]$$

The file loading cannot change neither the number of reactors nor the number of sites; in addition the reactor types must be previously declared. Delay and D&D parameters validity are not checked, so the User must be sure that the inserted data are valid; for this reason the User is asked for a confirmation before proceeding with the data import. In case of errors in these data the execution continues, but errors may occur.

As the parameters of a triangular distribution are not compatible with the ones of the other distributions, when changing the menu selection from or to triangular distribution, the parameters for that distribution are deleted.

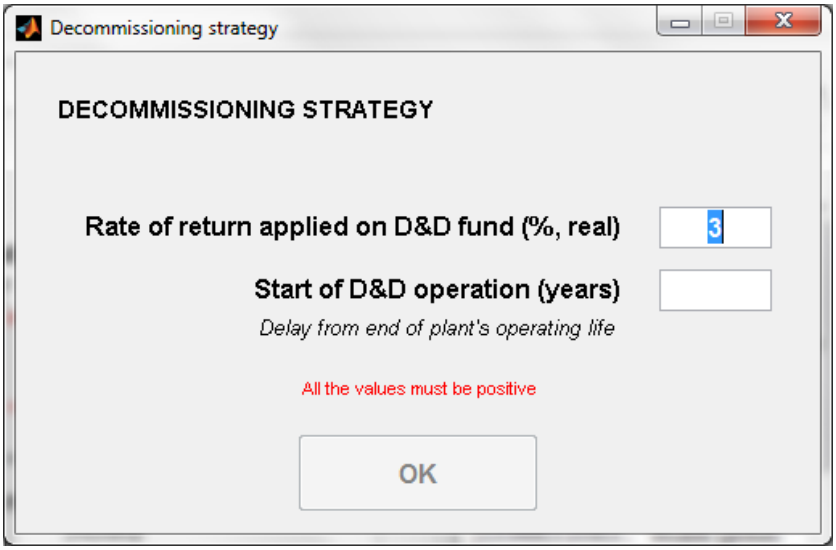
When the **Back** button is clicked, the inserted data are kept.

Decommissioning strategy

Window display

Accessible from Construction Schedule *(stochastic calculation only)*.

Screenshot


Decommissioning strategy
DECOMMISSIONING STRATEGY
Rate of return applied on D&D fund (%, real)
3
Start of D&D operation (years)
Delay from end of plant's operating life
All the values must be positive
OK

Aim

The User interface allows changing the decommissioning strategy for the selected reactor.

Operating method

The User should fill the **edit boxes** with the required value; they must be positive, otherwise the violating edit box is shaded in red and the User cannot get back to the Construction schedule window by means of the **OK** button.

Differences between deterministic and stochastic calculation

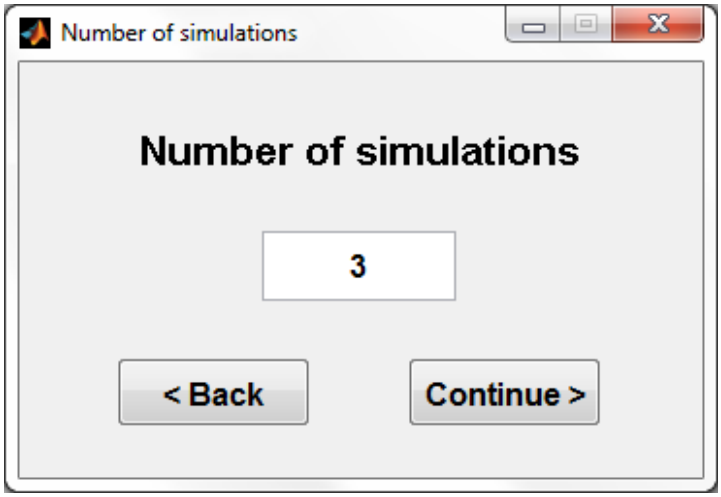
The form is not used in deterministic calculation.

Number of simulations

Window display

After Construction Schedule *(stochastic calculation only)*.

Screenshot



Aim

The User interface allows inserting the number of simulations to be performed.

Operating method

The User should fill the **edit box** with the required data; it must be positive, otherwise the box is shaded in red. Once the edit box has been properly filled, the User can pass to the following input window (Input Finalization) by clicking **Continue**. It is always possible to go back to the Construction Schedule by means of the **Back** button.

Differences between deterministic and stochastic calculation

The form is not used in deterministic calculation.

Input Finalization

Window display

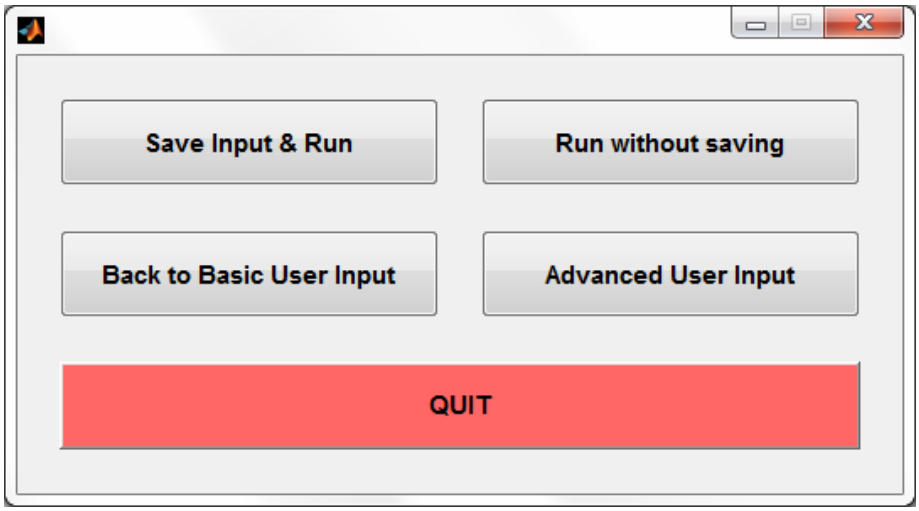
After Construction Schedule *(for deterministic calculation)*;

After Number of simulation *(for stochastic calculation)*;

After Iterative calculation settings.

Back from Learning.

Screenshot



Aim

This User interface is displayed after the Basic User Input or the Advanced User Input is finished.

The window presents to the User the choice between:

- saving the inserted data in a MAT file and run the calculation;
- running the calculation without saving the input data;
- checking the data inserted in the Basic Input section;
- continuing the input process with the Advanced section.

Operating method

The User may choose between 4 buttons:

- **Save Input & Run**: the User is asked for the path and the name to give to the scenario input MAT file; then, the file is saved, the current window is closed, and the calculation starts.
- **Run without saving**: closes the current window and the calculation starts.
- **Back to Basic User Input**: closes the current window and opens the Reactor Library window;
- **(Back to) Advanced User Input**: closes the current window and opens the Learning window;

Differences between deterministic and stochastic calculation

None.

Additional details

The caption of the last button changes depending on the previous window.

Distribution parameters (non-triangular distributions)

Window display

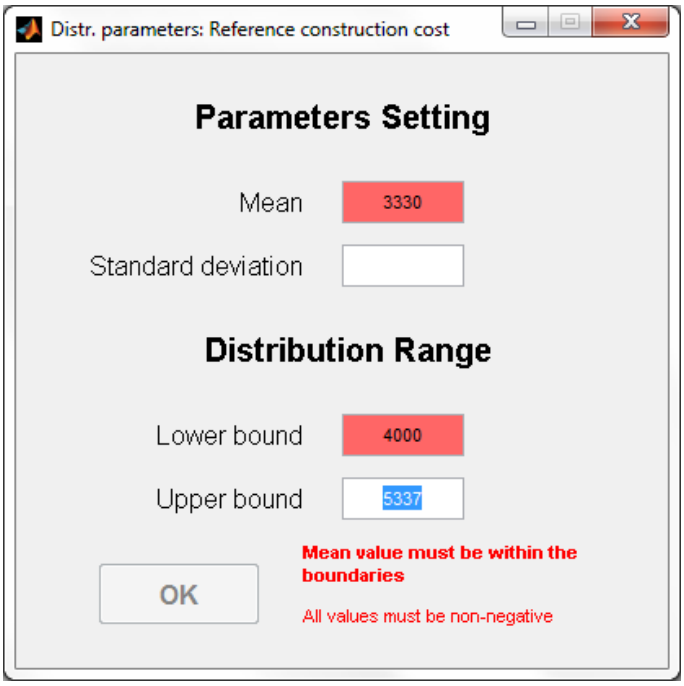
Accessible from Reactor Data Set *(stochastic calculation only)*;

Accessible from Investment Input *(stochastic calculation only)*;

Accessible from Country Input *(stochastic calculation only)*;

Accessible from Construction Schedule *(stochastic calculation only)*;

Screenshot



Aim

The User interface is opened whenever the distribution parameters (except for triangular ones) must be modified, i.e. after clicking a **Check/Set/Verify parameters** button.

Operating method

The User should fill the **edit boxes** with the required data, complying with the corresponding constraints; failing this, the violating edit box is shaded in red and the violated constraint is written in bold.

Once every edit box has been properly filled the User can get back to the calling window by means of the **OK** button.

Differences between deterministic and stochastic calculation

The form is not used in deterministic calculation.

Additional details

By default, all the values of the distribution must be positive; however, for the distributions listed below, this constraint does not apply; in any case, the standard deviation must be non-

negative. The distributions whose boundaries are relaxed are:

- Annual escalation rate for construction cost
- Annual increase of delay-influenced construction cost
- Annual inflation rate
- Construction delay

Mean value must always be between the lower and higher boundaries; if the chosen distribution is the uniform one (and so mean and standard deviation cells are disabled), this limitation is reduced to the fact that the lower bound must be lower than the higher bound.

Distribution parameters (triangular distributions)

Window display

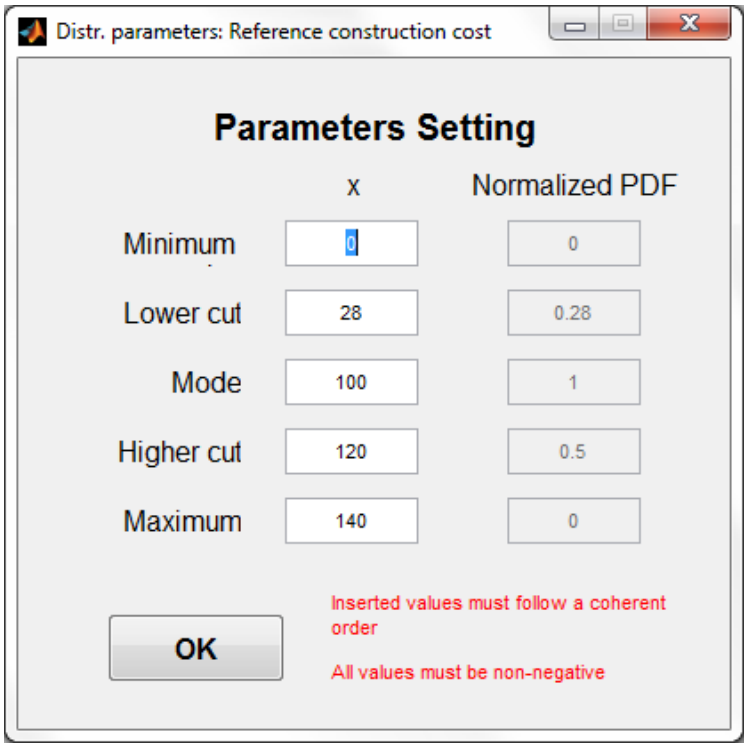
Accessible from Reactor Data Set *(stochastic calculation only)*;

Accessible from Investment Input *(stochastic calculation only)*;

Accessible from Country Input *(stochastic calculation only)*;

Accessible from Construction Schedule *(stochastic calculation only)*;

Screenshot

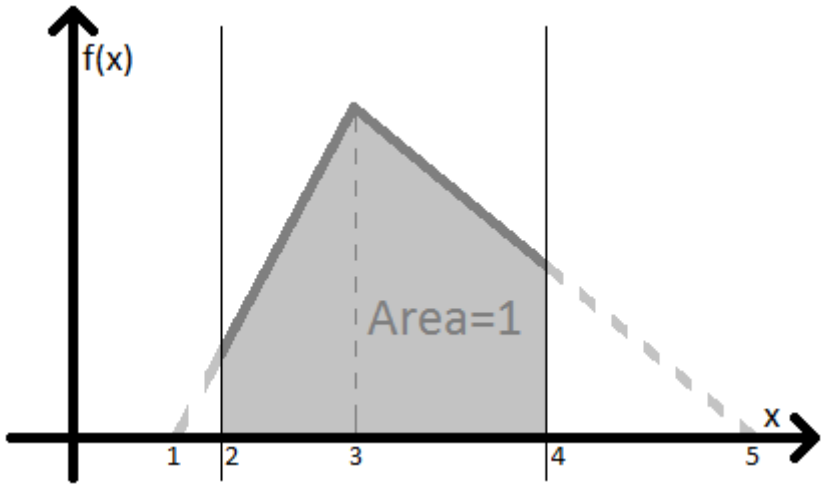


Aim

The User interface is opened whenever the parameters of a triangular distribution must be modified, i.e. after clicking a **Check/Set/Verify parameters** button.

Operating method

This function reads the parameters only for the triangular distribution cut at the two sides, shown in the following picture.



The User should fill the **edit boxes** with the required data, complying with the corresponding constraints; failing this, the violating edit box is shaded in red and the violated constraint is written in bold.

Once all the edit boxes have been properly filled, the normalized value of f(x) is given for each point.

Once every edit box has been properly filled the User can get back to the calling window by means of the **OK** button.

Differences between deterministic and stochastic calculation

The form is not used in deterministic calculation.

Additional details

By default, all the values of the distribution must be positive; however, for the distributions listed below, this constraint does not apply; in any case, the standard deviation must be positive. The distributions whose boundaries are relaxed are:

- Annual escalation rate for construction cost
- Annual increase of delay-influenced construction cost
- Annual inflation rate
- Construction delay

It must always be true that Minimum ≤ Lower cut ≤ Mode ≤Higher cut ≤ Maximum.

ADVANCED INPUT

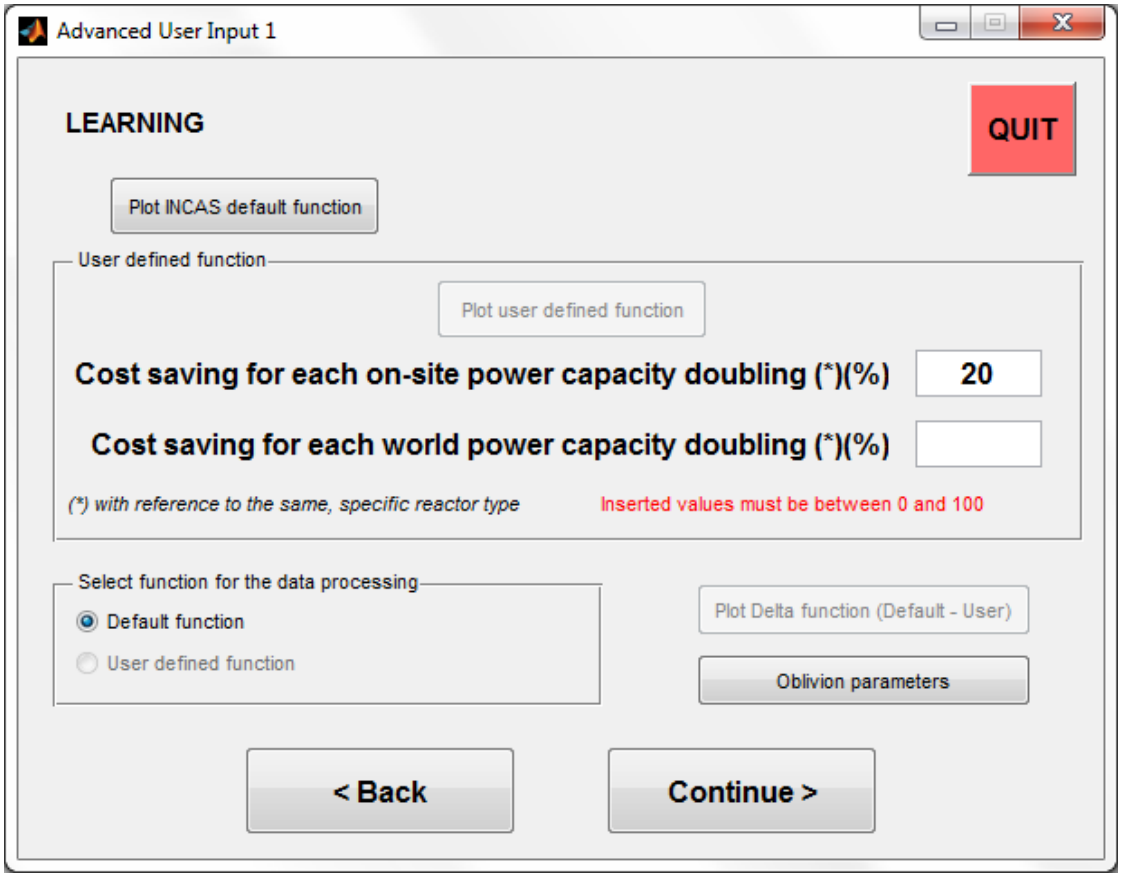
Learning

Window display

After Input Finalization, once chosen **Advanced User Input**;

Back from Modularization.

Screenshot


Advanced User Input 1
LEARNING
QUIT
Plot INCAS default function
User defined function
Plot user defined function
Cost saving for each on-site power capacity doubling (*)(%)
20
Cost saving for each world power capacity doubling (*)(%)
(*) with reference to the same, specific reactor type
Inserted values must be between 0 and 100
Select function for the data processing
Default function
User defined function
Plot Delta function (Default - User)
Oblivion parameters
< Back
Continue >

Aim

This window allows modifying the default parameters for the learning factor calculation.

Operating method

The default learning function can be substituted by a User-defined one, which requires 2 parameters to be put in the **edit boxes**. The values to be inserted are percentages and so must be included between 0 and 100; edit boxes not compliant to this constraint will be shaded in red.

Once both edit boxes have been properly filled the User will be given the choice between default and User-defined function, expressed in the proper **panel**, and plotting the User-defined function will be possible. It will be also possible to plot the difference between the User-defined function and the default one.

The User can always see the plot of the default learning function by using the **Plot INCAS default function** button. When a plot button is clicked with another plot figure open, the two plots will be superposed for comparison.

The User can modify the **oblivion parameters** by means of the special button, which will open a dedicated window (Learning oblivion parameters).

It is always possible to move to the next window (Modularization) by clicking **Continue** or to go back to the Input Finalization by means of the **Back** button.

Differences between deterministic and stochastic calculation

None.

Additional details

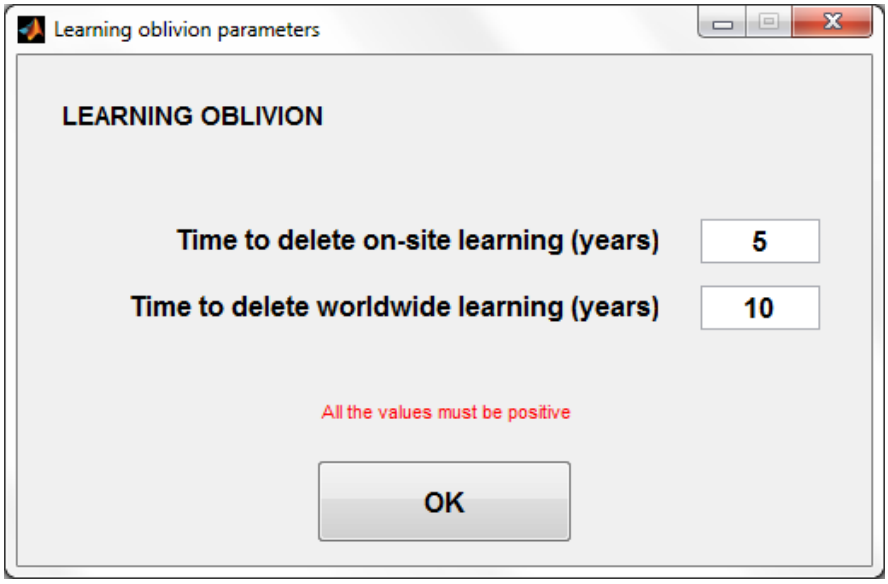
When the **Back** button is clicked, the inserted data are kept.

Learning oblivion parameters

Window display

Accessible from Learning.

Screenshot



Aim

This User interface allows changing the oblivion parameters.

Operating method

The User should fill the **edit boxes** with the required value; they must be positive, otherwise the violating edit box is shaded in red and the User cannot get back to the Learning window by means of the **OK** button.

Differences between deterministic and stochastic calculation

None.

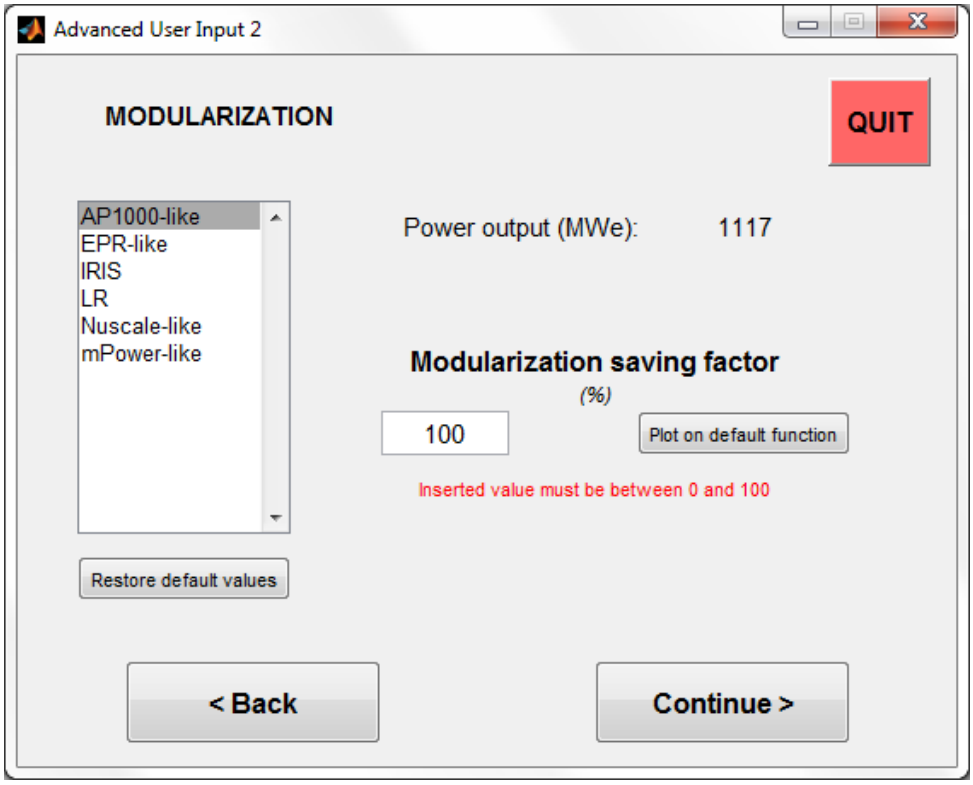
Modularization

Window display

After Learning;

Back from Multiple units.

Screenshot



Aim

This User interface allows defining custom modularization values for each reactor type, different from the ones calculated automatically, which are dependent on the reactor power.

Operating method

The list on the left side shows the reactors in the library and can be used to select the reactor to take into consideration. The power output of the selected reactor is displayed and the modularization factor (the default one if never modified) is shown in the **edit box**. The modularization is a percentage and so it must be included between 0 and 100; failing this, the violating edit box is shaded in red and the violated constraint is written in bold. In addition, the User cannot modify any other reactor than the selected one.

It is possible to plot the modularization values of all the reactors in the library on the default function by clicking on **Plot on default function**.

Also, it is always possible to reset the default modularization values for all the reactors by means of **Restore default values**.

Once every edit box has been properly filled the User can pass to the following input window (Multiple units) by clicking **Continue**. It is always possible to go back to the Learning window

by means of the **Back** button.

Differences between deterministic and stochastic calculation

None.

Additional details

When the **Back** button is clicked, the inserted data are kept.

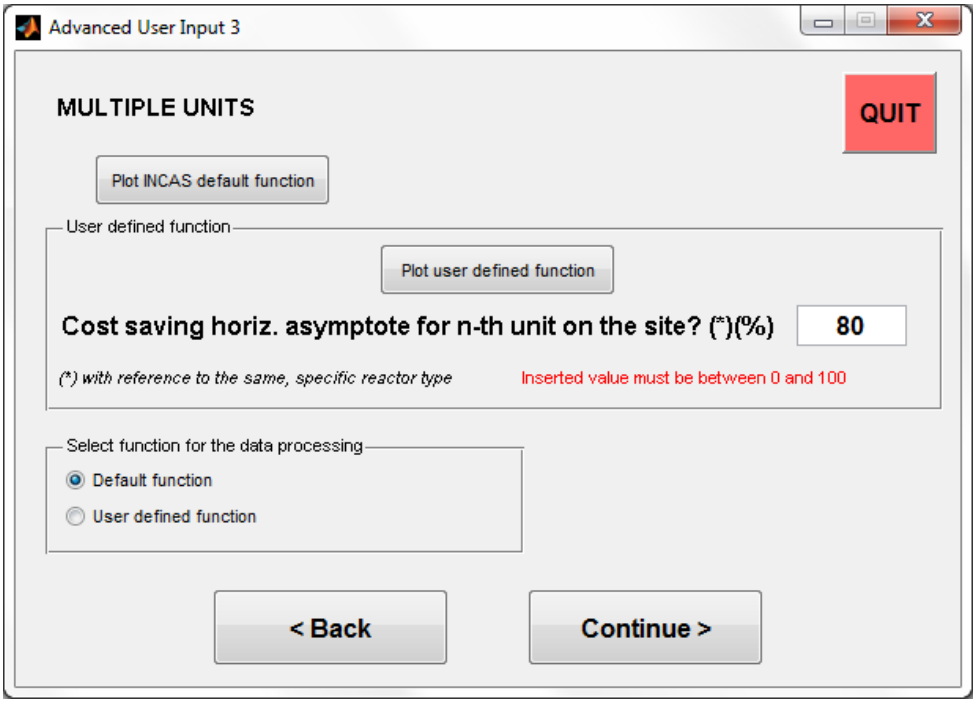
Multiple units

Window display

After Modularization;

Back from Iterative calculation settings.

Screenshot


Advanced User Input 3
MULTIPLE UNITS
QUIT
Plot INCAS default function
User defined function
Plot user defined function
Cost saving horiz. asymptote for n-th unit on the site? (*)(%)
80
(*) with reference to the same, specific reactor type
Inserted value must be between 0 and 100
Select function for the data processing
Default function
User defined function
< Back
Continue >

Aim

This window allows modifying the default parameters for the multiple-unit factor calculation.

Operating method

The default multiple-unit function can be substituted by a User-defined one, which requires a parameters to be put in the **edit box**. The needed value is a percentage and so must be included between 0 and 100; if the edit boxes does not comply with this constraint it will be shaded in red.

Once the edit box has been properly filled the User will be given the choice between default and User-defined function, expressed in the proper **panel**, and plotting the User-defined function will be possible.

The User can always see the plot of the default multiple-unit function by using the **Plot INCAS default function** button. When a plot button is clicked with another plot figure open, the two plots will be superposed for comparison.

It is always possible to move to the next window (Iterative calculation settings) by clicking **Continue** or to go back to the Modularization by means of the **Back** button.

Differences between deterministic and stochastic calculation

None.

Additional details

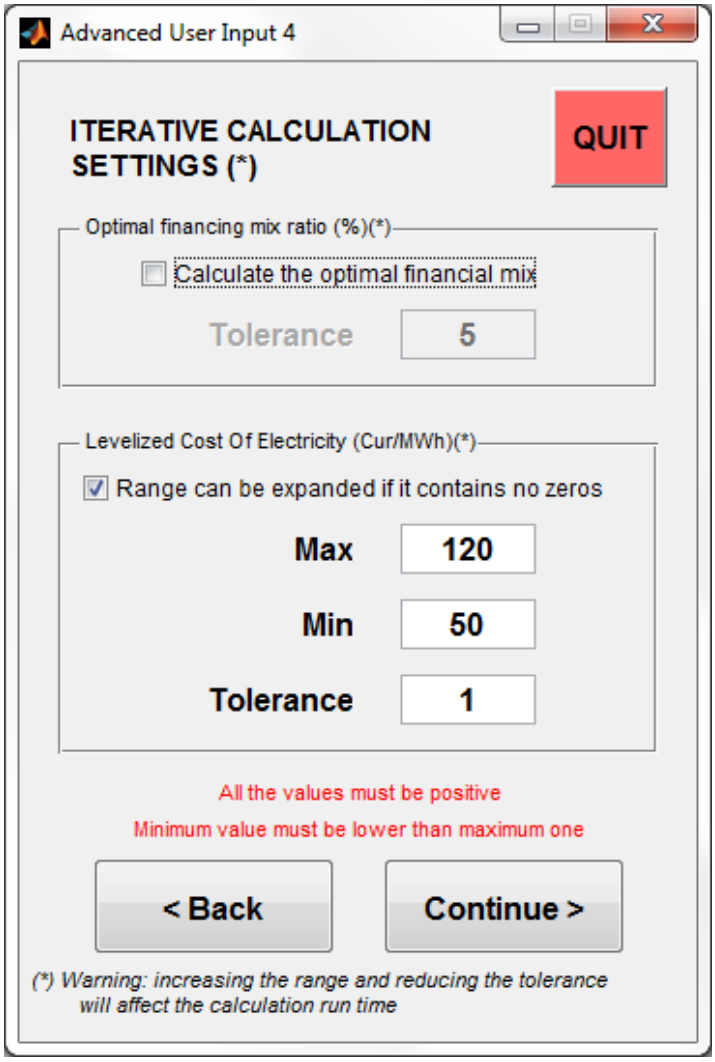
When the **Back** button is clicked, the inserted data are kept.

Iterative calculation settings

Window display

After Multiple units.

Screenshot



Aim

Optimal financial mix and LUEC are calculated using iterative methods; In this window the User is asked to introduce the tolerance that will be used for stopping the iterations and a guess interval for LCOE.

Operating method

The User should fill the **edit boxes** with the required data, complying with the given constraints; failing this, the violating edit box is shaded in red and the violated constraint is written in bold. In addition, the User cannot continue to the next window.

For LCOE calculation, an initial guess interval is required; however, if the **checkbox** is enabled, in case no solution can be found in the given interval, INCAS will move or expand it; on the contrary, if the checkbox has been unchecked, if no solution can be found in the given interval,

INCAS will not return the LCOE among the result.

As the optimal financial mix calculation may be long, the User can exclude it using the **checkbox**; the checkbox is always unchecked and disabled if the cost of debt is fixed by the User.

Once every edit box has been properly filled the User can pass to the following input window (Input Finalization) by clicking **Continue**. It is always possible to go back to the Multiple units by means of the **Back** button.

Differences between deterministic and stochastic calculation

As in stochastic calculation the financing mix is not calculated, the related section is visible only in the deterministic case.

Additional details

When the **Back** button is clicked, the inserted data are kept.

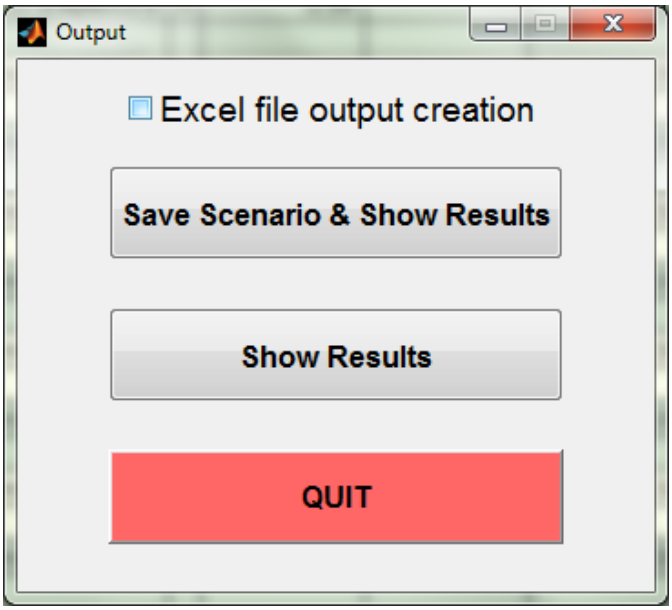
OUTPUT

Output Options

Window display

As soon as the calculation is completed.

Screenshot



Aim

This User interface is displayed when the calculation procedure has been completed.

The window presents to the User the choice between:

- saving the input scenario and the results in a MAT file and then show the latter;
- showing the results without saving them.

In both cases, the User may choose to create an Excel file summarizing the scenario and the results.

Operating method

The User may choose between 2 buttons:

- **Save Scenario & Show Results**: the User is asked for the path and the name to give to the scenario input&output MAT file; then, the file is saved, the current window is closed, and the results are shown.
- **Show results**: closes the current window and shows the results.

In addition, if **Excel file output creation** is checked, an Excel file summarizing input and output data is created in the position chosen by the User; in this case a progress bar will be shown while the file is created.

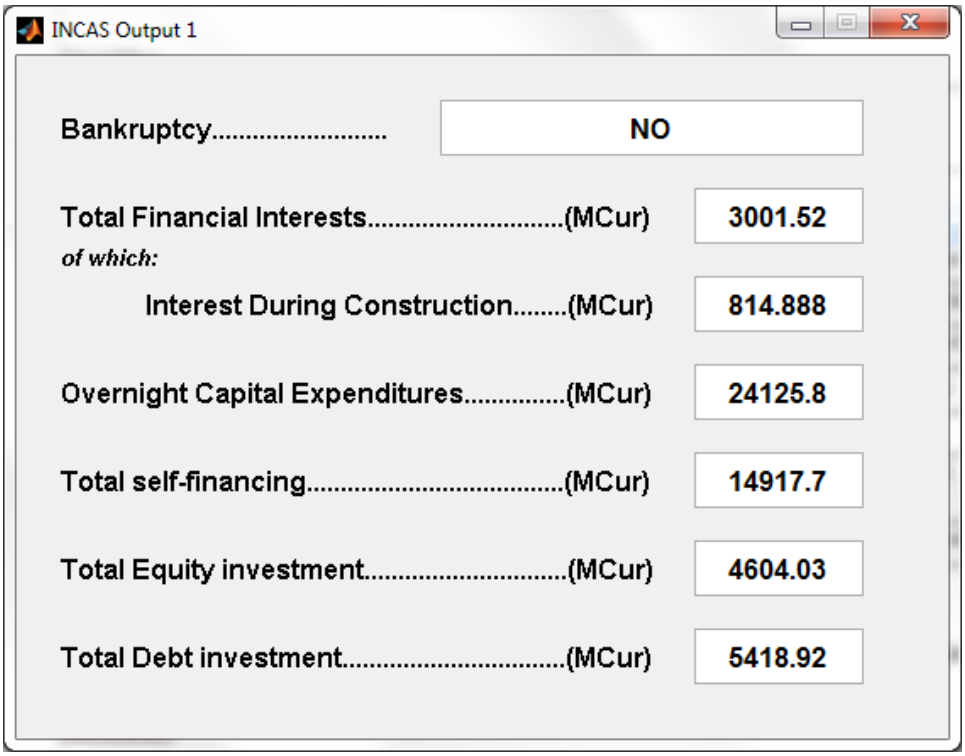
Differences between deterministic and stochastic calculation

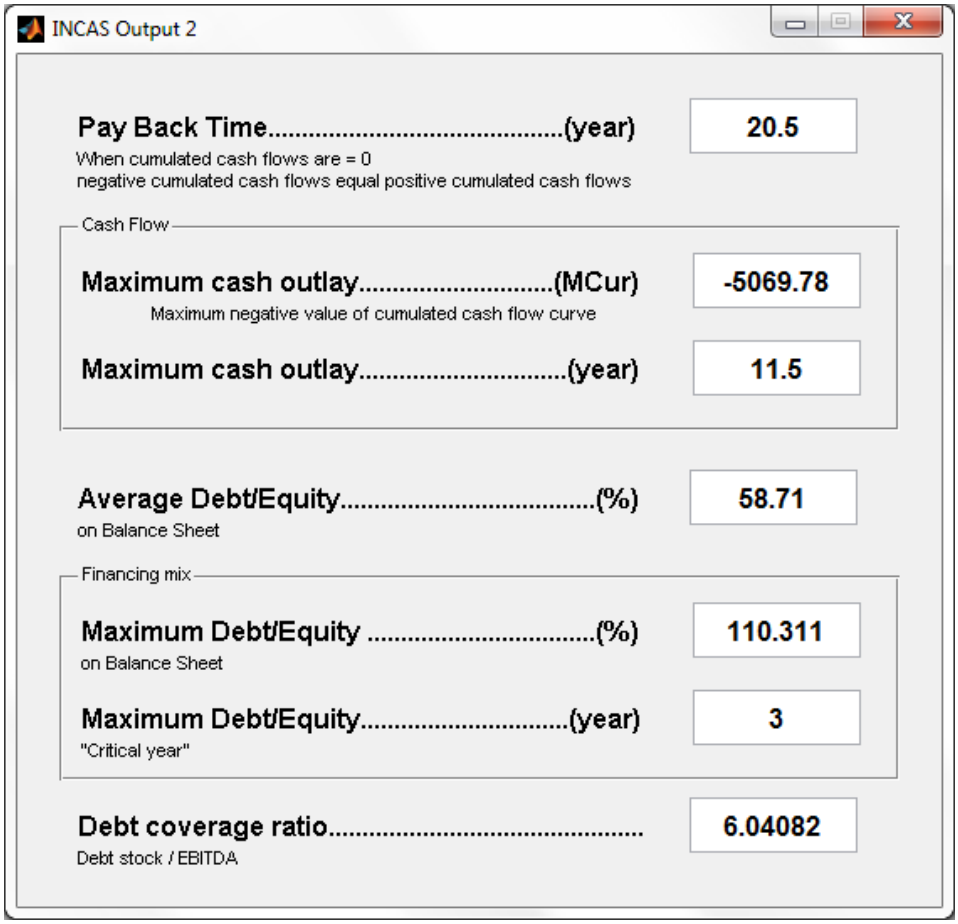
None.

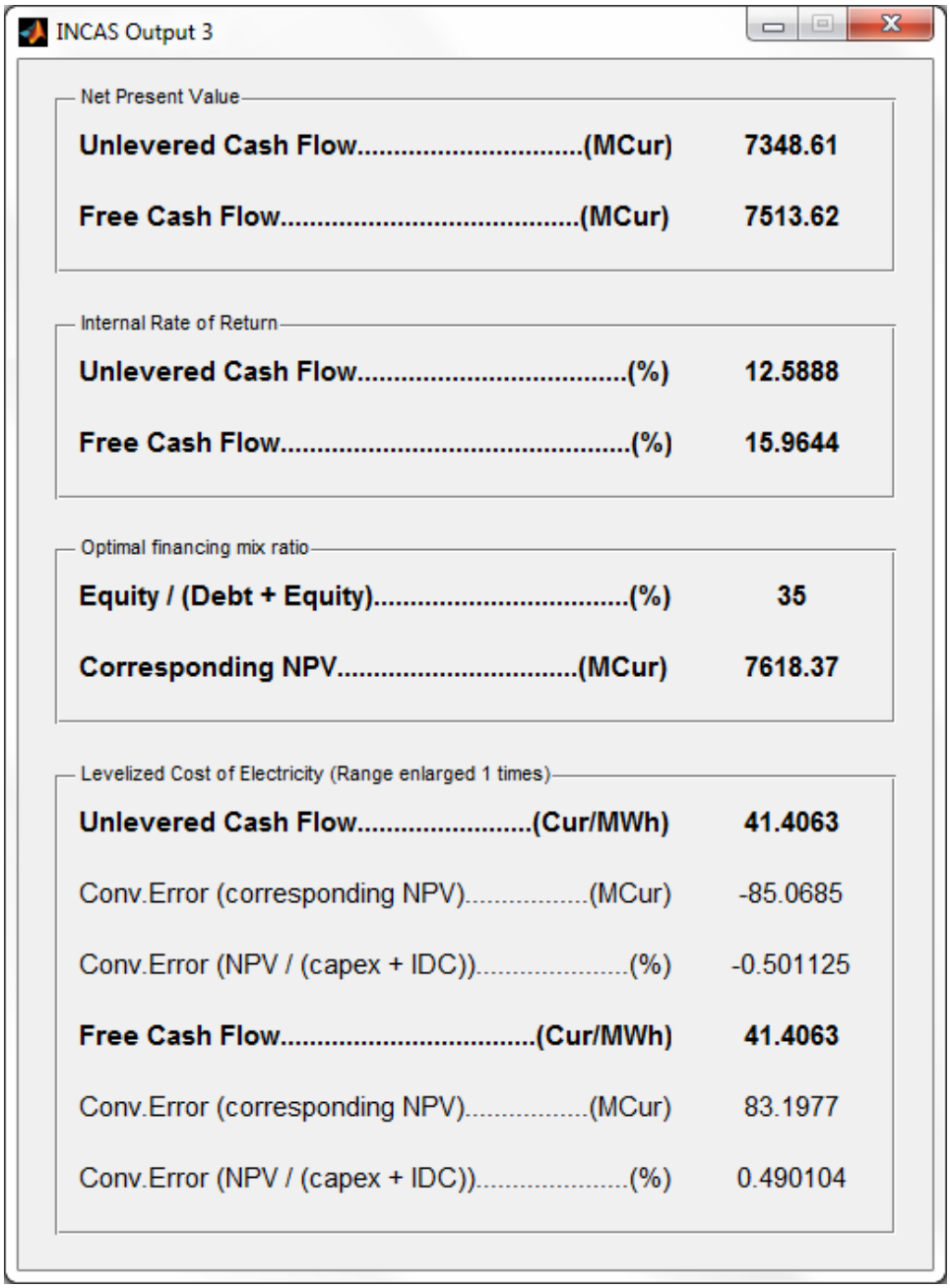
INCAS Output

At the end of the calculation 3 result windows are created.

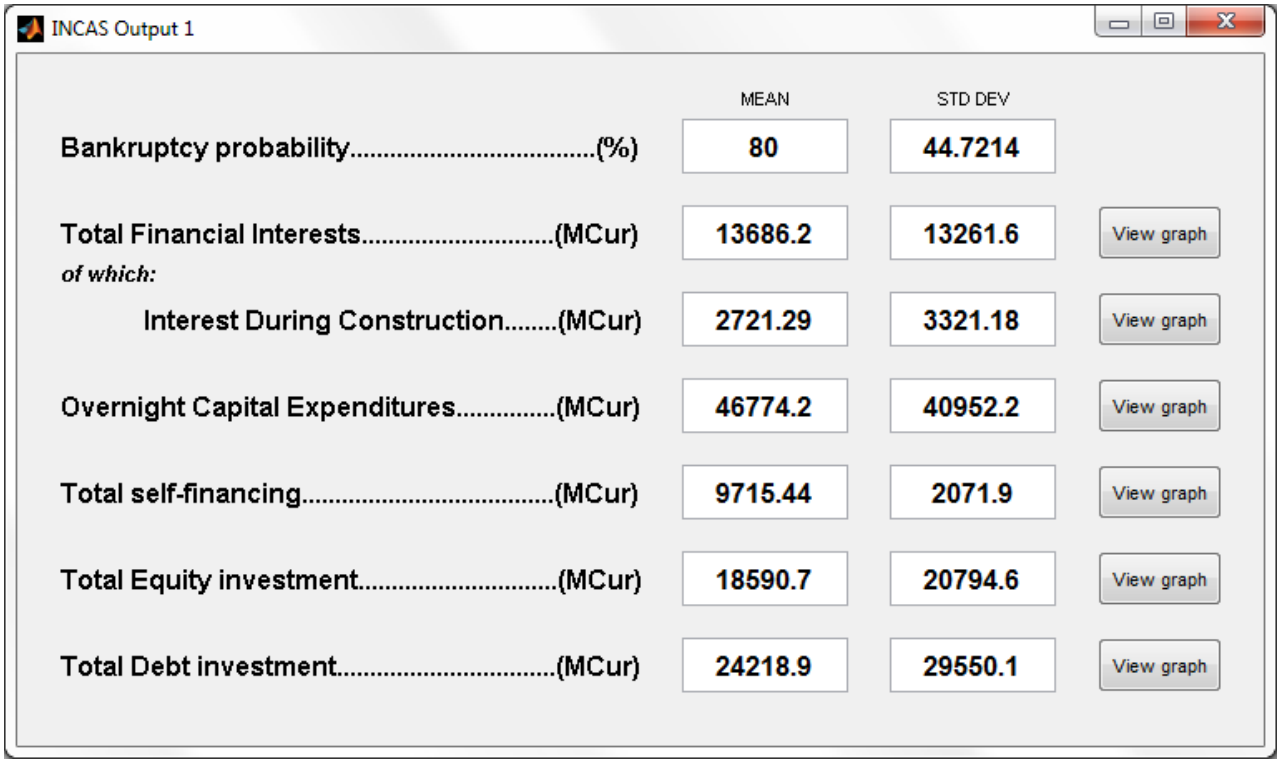
Screenshot (deterministic)

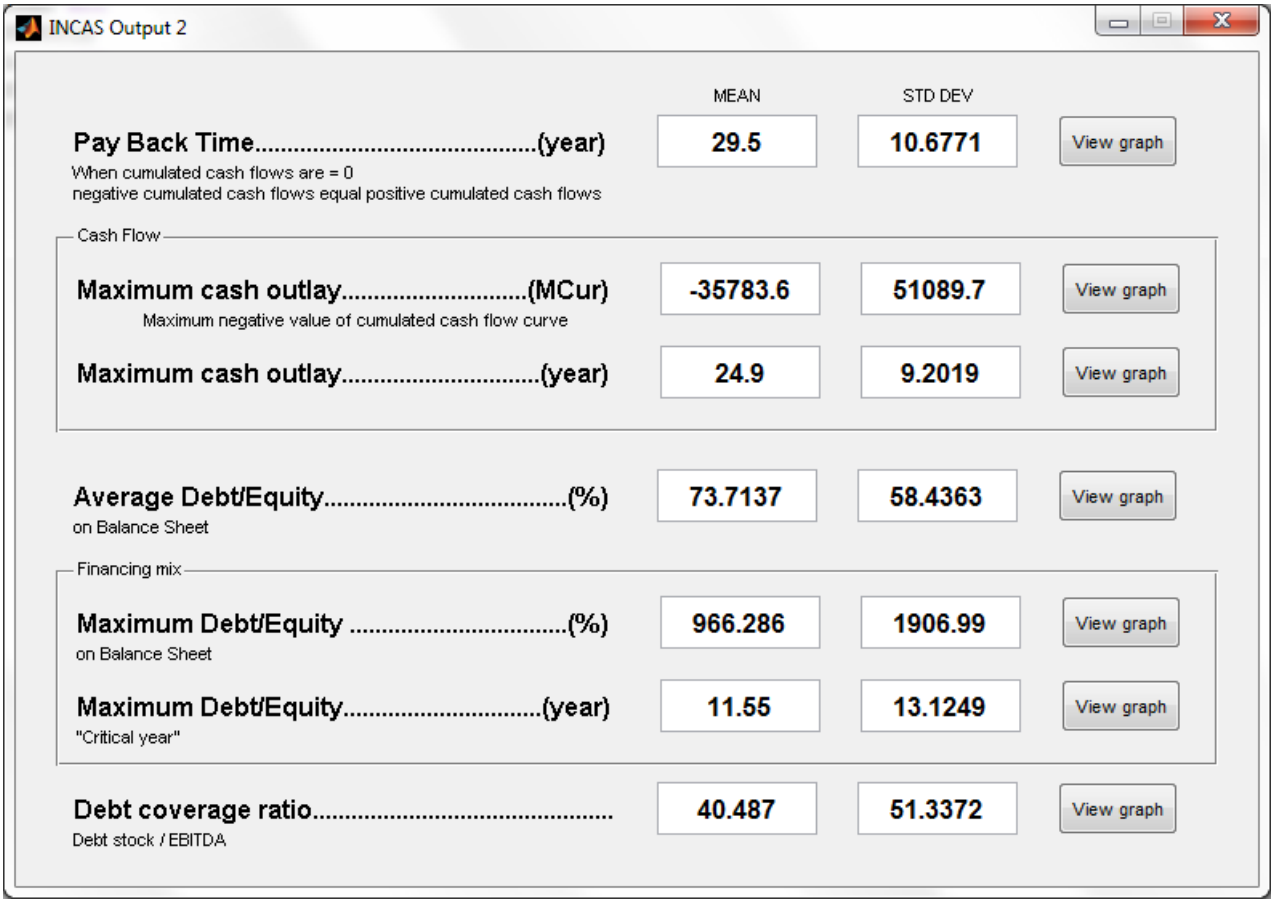


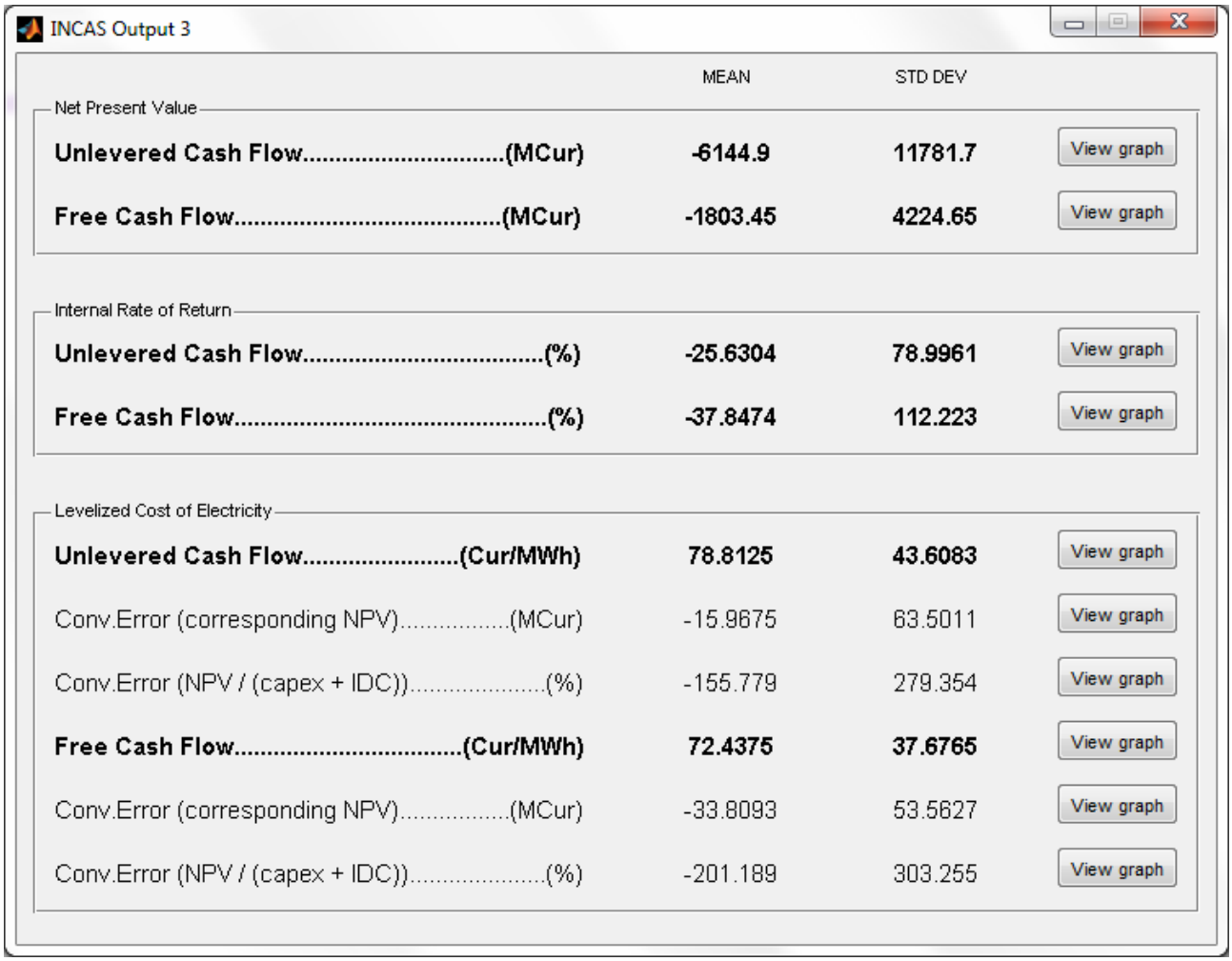

INCAS Output 2
Pay Back Time.....(year)
20.5
When cumulated cash flows are = 0
negative cumulated cash flows equal positive cumulated cash flows
Cash Flow
Maximum cash outlay.....(MCur)
-5069.78
Maximum negative value of cumulated cash flow curve
Maximum cash outlay.....(year)
11.5
Average Debt/Equity.....(%)
58.71
on Balance Sheet
Financing mix
Maximum Debt/Equity .....(%)
110.311
on Balance Sheet
Maximum Debt/Equity.....(year)
3
"Critical year"
Debt coverage ratio.....
6.04082
Debt stock / EBITDA


INCAS Output 3
Net Present Value
Unlevered Cash Flow.....(MCur) 7348.61
Free Cash Flow.....(MCur) 7513.62
Internal Rate of Return
Unlevered Cash Flow.....(%) 12.5888
Free Cash Flow.....(%) 15.9644
Optimal financing mix ratio
Equity / (Debt + Equity).....(%) 35
Corresponding NPV.....(MCur) 7618.37
Levelized Cost of Electricity (Range enlarged 1 times)
Unlevered Cash Flow.....(Cur/MWh) 41.4063
Conv.Error (corresponding NPV).....(MCur) -85.0685
Conv.Error (NPV / (capex + IDC)).....(%) -0.501125
Free Cash Flow.....(Cur/MWh) 41.4063
Conv.Error (corresponding NPV).....(MCur) 83.1977
Conv.Error (NPV / (capex + IDC)).....(%) 0.490104

Screenshot (stochastic)






INCAS Output 3
MEAN
STD DEV
Net Present Value
Unlevered Cash Flow.....(MCur) -6144.9 11781.7 View graph
Free Cash Flow.....(MCur) -1803.45 4224.65 View graph
Internal Rate of Return
Unlevered Cash Flow.....(%) -25.6304 78.9961 View graph
Free Cash Flow.....(%) -37.8474 112.223 View graph
Levelized Cost of Electricity
Unlevered Cash Flow.....(Cur/MWh) 78.8125 43.6083 View graph
Conv.Error (corresponding NPV).....(MCur) -15.9675 63.5011 View graph
Conv.Error (NPV / (capex + IDC)).....(%) -155.779 279.354 View graph
Free Cash Flow.....(Cur/MWh) 72.4375 37.6765 View graph
Conv.Error (corresponding NPV).....(MCur) -33.8093 53.5627 View graph
Conv.Error (NPV / (capex + IDC)).....(%) -201.189 303.255 View graph

Differences between deterministic and stochastic calculation

In the stochastic case, each result is associated with a standard deviation and has a **View graph** button that shows the frequency distributions of the obtained results in the various scenarios calculated throughout the MonteCarlo simulation.

Additional details

The values of the Output 1 are actualized.

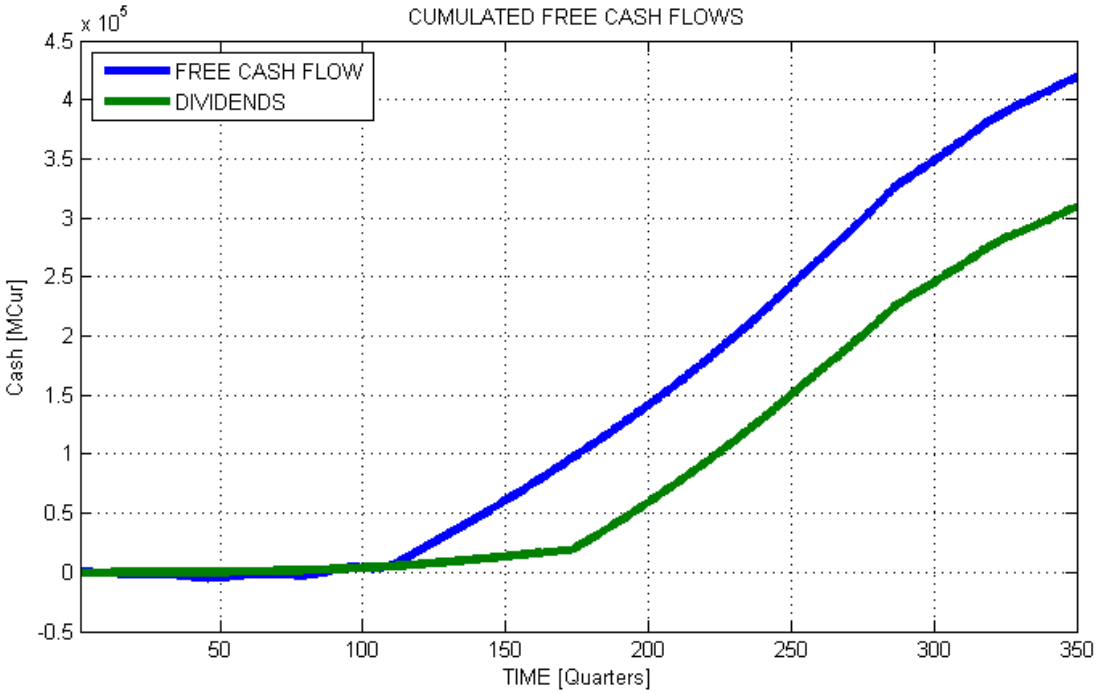
The caption of the LCOE panel reports a message in red if no zeros have been found.

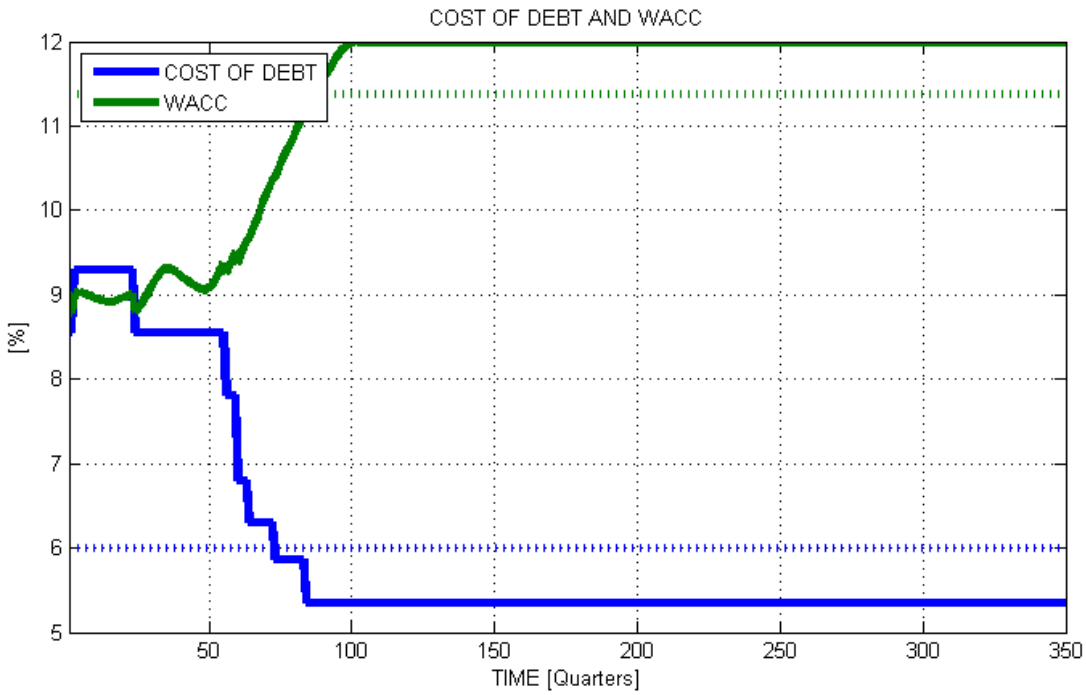
Output plots

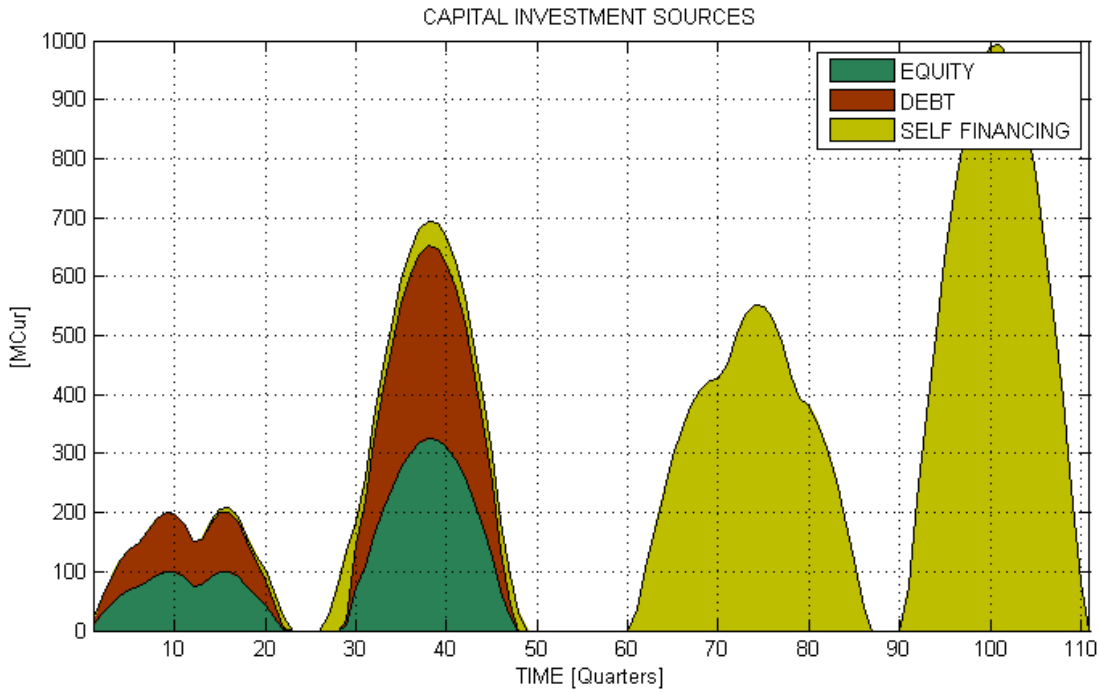
At the end of the calculation 6 plots are created:

- Line chart: Cumulated free cash flows / time;
- Line chart: Cost of debt / time and WACC / time;
- Area chart: Capital investment sources / time;
- Area chart: Debt stock / time;
- Line chart: Free cash flow / time and Dividends / time;
- Superposed bar chart: Capital investment sources / reactor;
- Line chart: NPV / financial mix.

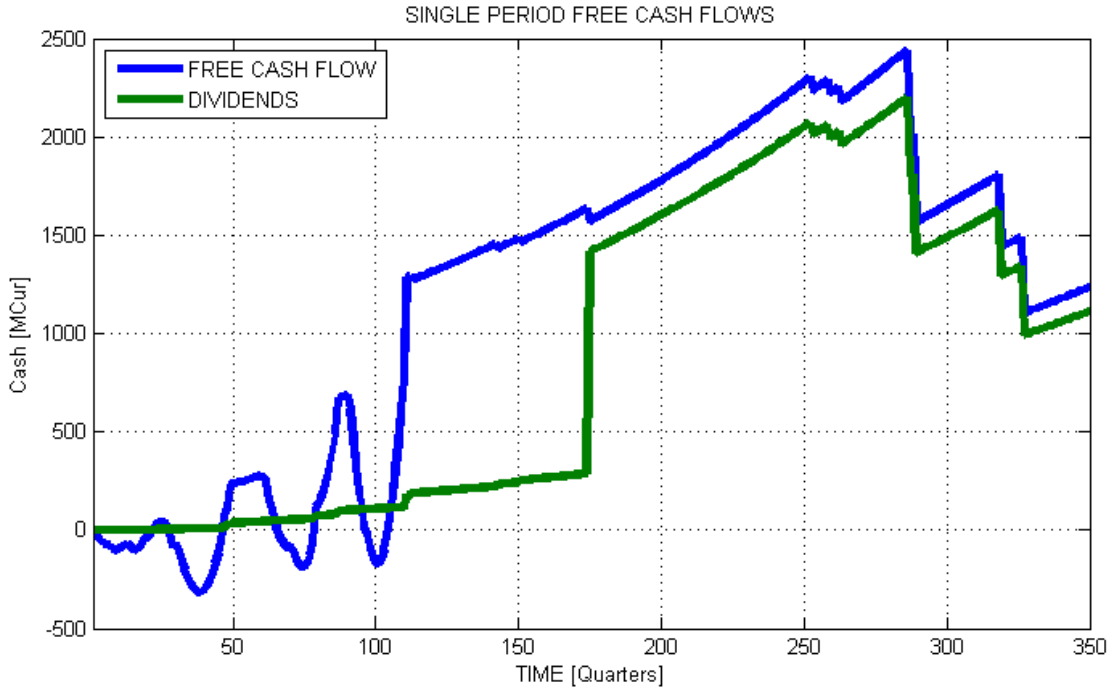
Screenshots

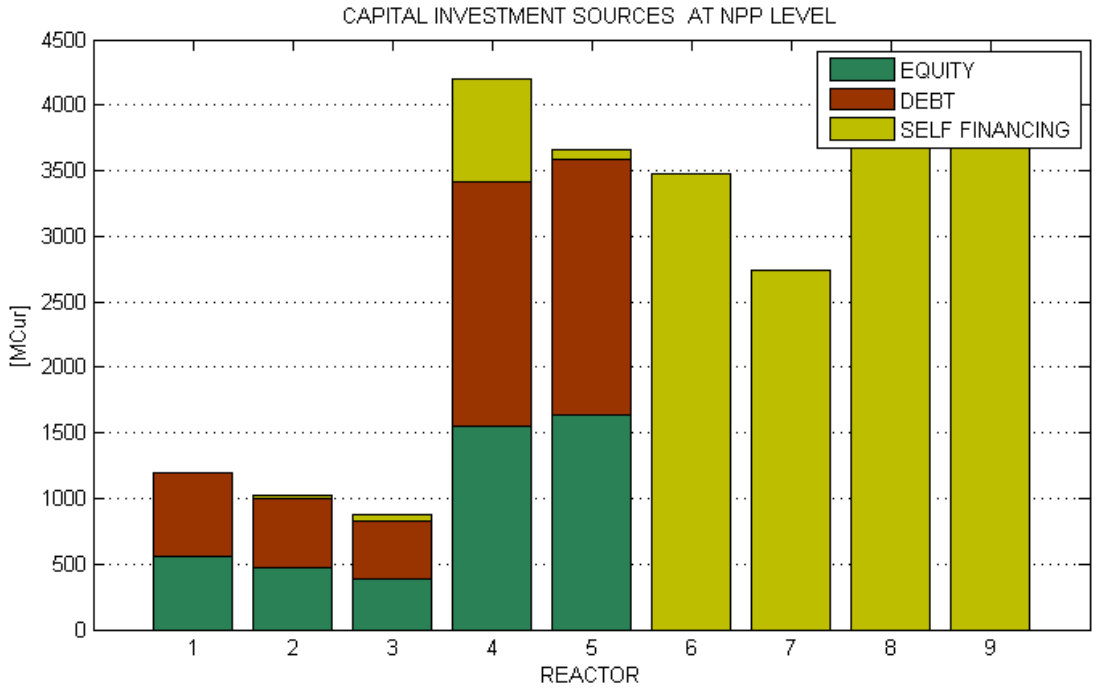


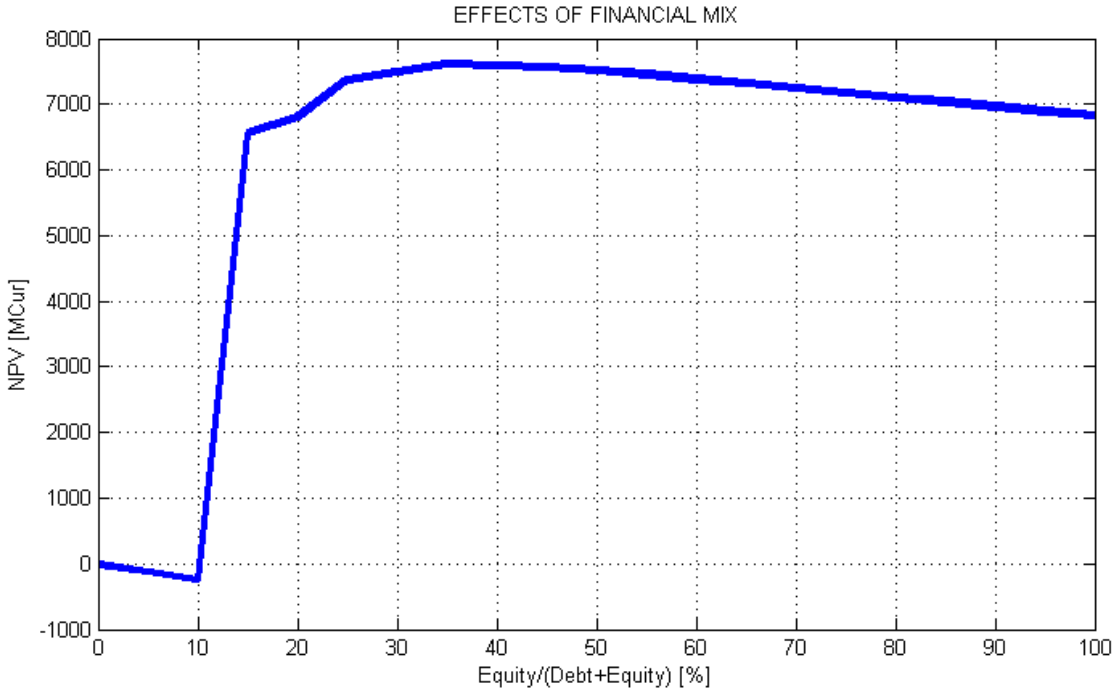

COST OF DEBT AND WACC
COST OF DEBT
WACC
[%]
TIME [Quarters]


CAPITAL INVESTMENT SOURCES
EQUITY
DEBT
SELF FINANCING
[MCur]
TIME [Quarters]

DEBT STOCK
Debt [MCur]
TIME [Quarters]
0
1000
2000
3000
4000
5000
6000
50
100
150
200
250
300
350


SINGLE PERIOD FREE CASH FLOWS
FREE CASH FLOW
DIVIDENDS
Cash [MCur]
TIME [Quarters]
-500
0
500
1000
1500
2000
2500
50
100
150
200
250
300
350


CAPITAL INVESTMENT SOURCES AT NPP LEVEL
EQUITY
DEBT
SELF FINANCING
[MCur]
REACTOR
0
500
1000
1500
2000
2500
3000
3500
4000
4500
1
2
3
4
5
6
7
8
9


EFFECTS OF FINANCIAL MIX
NPV [MCur]
Equity/(Debt+Equity) [%]
-1000
0
1000
2000
3000
4000
5000
6000
7000
8000
0
10
20
30
40
50
60
70
80
90
100

INCAS main publications:

"Financial case studies on Small- and Medium-size Modular Reactors", S. Boarin, G. Locatelli, M. Mancini, M.E. Ricotti, NUCLEAR TECHNOLOGY, vol. 178, p. 218-232 (2012)

"Investment in different sized SMRs: economic evaluation of stochastic scenarios by INCAS code", S. Barenghi, S. Boarin , M.E. Ricotti, ICAPP Int. Conf., Chicago (USA), 24/6/2012, p. 2783-2792, ANS Ed.

"Small–medium sized nuclear coal and gas power plant: a probabilistic analysis of their financial performances and influence of CO2 cost", G. Locatelli, M. Mancini, ENERGY POLICY, vol. 38, p. 6360–6374 (2010)

"Economic features of integral, modular, small-to-medium size reactors", M.D. Carelli, P. Garrone, G. Locatelli, M. Mancini, C. Mycoff, P. Trucco, M.E. Ricotti, PROGRESS IN NUCLEAR ENERGY, pp.403-414, vol.52, 4 (2010)

INCAS code is offered free-of-charge to Universities, Research Centres and Institutions, for non-commercial purposes, upon the signature of a Collaboration Agreement with POLIMI.

Contact us

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sara.boarin@polimi.it

Further info and documents

INCAS web site:
www.nuclearenergy.polimi.it/research/incas.php

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